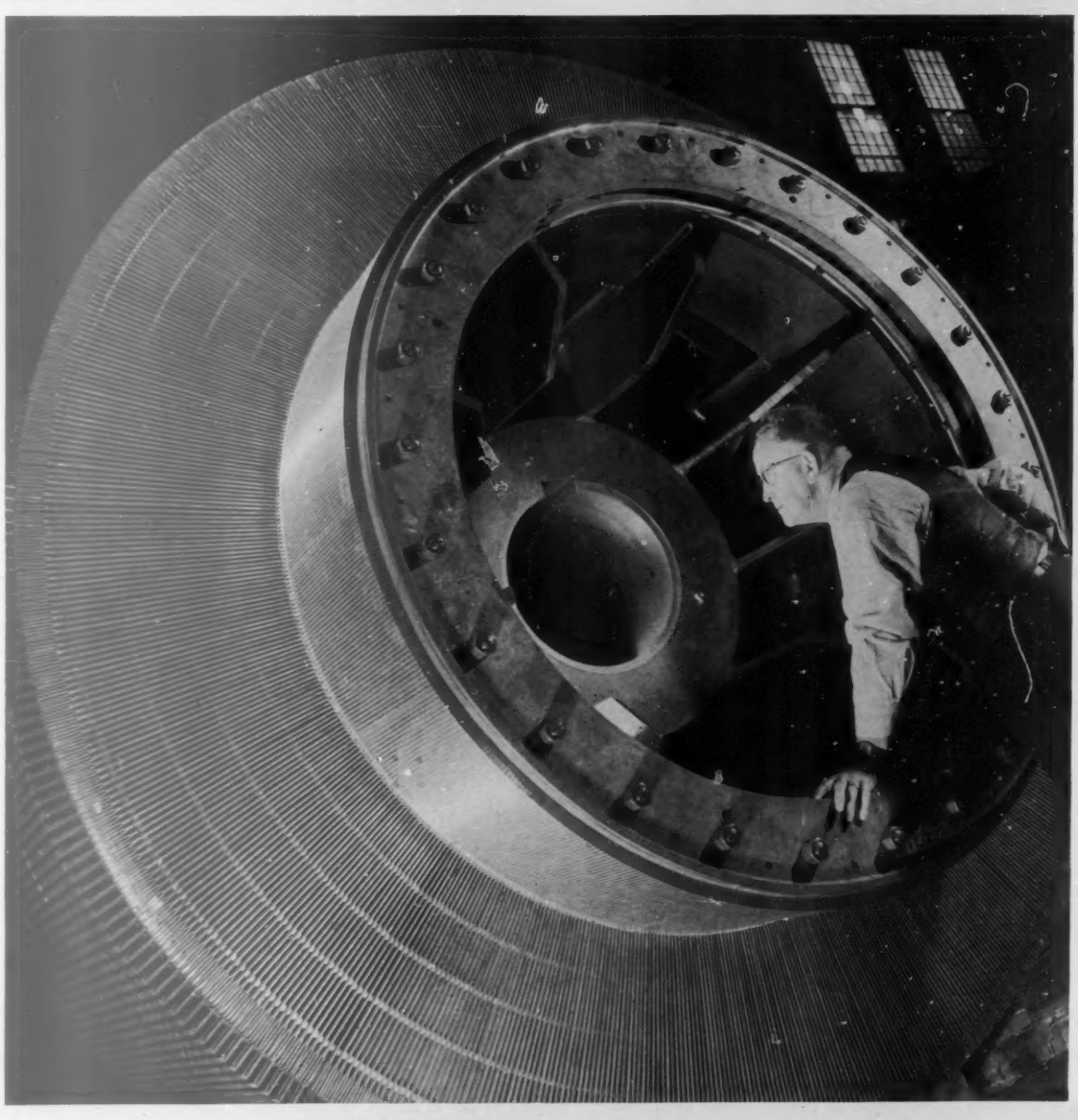
ALLIS-CHALMERS Electrical REVIEW



Second Quarter, 1947

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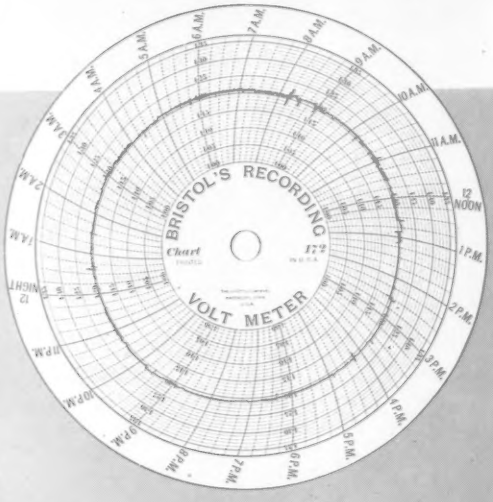

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Large steam demands justify installation and subsequent enlargement of superimposed power plants.

Shell's New Superimposed Power Plant

PAUL L. ANDRY, JR.
Utilities Engineer,
Manufacturing-Engineering Department,
Shell Oil Company, Inc.
New York, New York

FIGURE 1

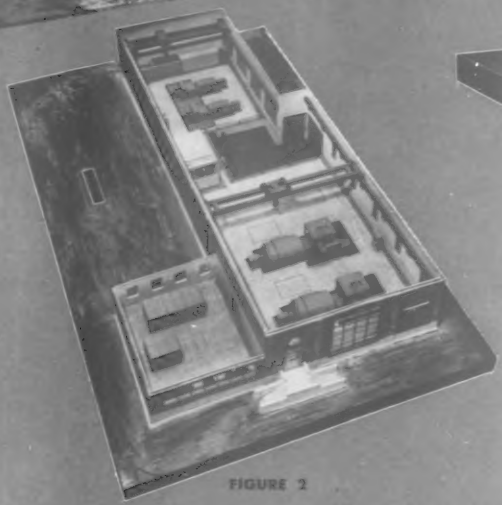


FIGURE 2

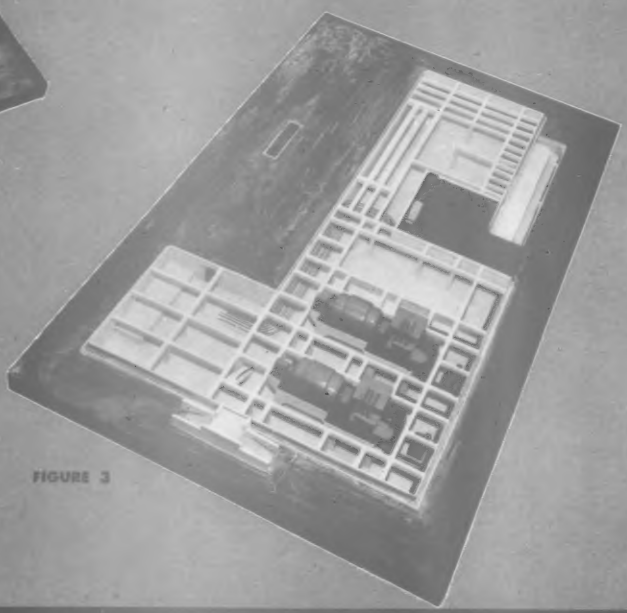


FIGURE 3

RAPID industrial development in and about the city of Houston has contributed considerably to its phenomenal growth evidenced by the approximate 150 percent increase in population since 1929, when Shell's Houston Refinery was initially operated. In step with the city, both in rate of expansion and new developments, are Shell's petroleum refining and chemical plants located about 20 miles from the city at Deer Park on the Houston Ship Channel, which has been a vital factor in the city's development. They are within view of the towering San Jacinto Monument, which commemorates Sam Houston's 1836 victory over Mexico's Santa Ana on the battlefield where Texas won her independence. Among the advantages prominently responsible for selecting this site were the nearness to abundant crude oil production and the economical transportation of both crude oil and products via pipe lines, ocean-going tankers, and barges. In addition, natural gas for fuel is readily available, thereby permitting the processing of practically all of the crude oil intake into finished products.

The refinery processes about 100,000 barrels per day of crude petroleum and produces motor and aviation gasolines, fuel oils, kerosene, diesel oils, solvents and other petroleum products. Shell chemical processes supplement the petroleum refining plants and utilize by-product gases formerly consumed as fuel for the manufacture of a large number of petroleum-derived chemicals or left to waste in the oil fields.

Starting with the first commercial butadiene plant in the nation's synthetic rubber program and one to supply wartime needs for isopropryl alcohol and acetone, the chemical processes have since been expanded manyfold. New plants are producing other alcohols, ketones, D-D soil fumigants, and a number of solvents and intermediate chemicals for the manufacture of surface coatings, plastics, and various industrial materials. Included among the new chemical plants now under construction is one for the manufacture of synthetic ethyl alcohol and another for synthetic glycerine.

A new fluid bed Catalytic Cracking Plant supplements the older thermal cracking plants and extensive lubricating oil plants are in early stages of construction.

The supply of process steam (at 175-200 psig) and electric power to these many developments led to the consideration of superimposed turbine generators. The advantages of this type of installation have been realized for many years, and, in 1936-1937, two 2,500 kw turbine-generators and accompanying boilers were installed. These were designed for 450 psig and 650 F steam inlet, 200 psig exhaust and electric power generation at 2,300 volts, 3 phase, 60 cycles. They were supplemented by purchased electric power supplied at a primary voltage of 12,000 v.

Models help determine ideal layout

As the newer petroleum and chemical processes were developed, their electric power requirements were found to be considerably in excess of the power which can be generated by superimposed turbine-generators with inlet steam at 450 psig. A study of the economics of higher pressure turbine-generators resulted in the decision to increase the steam generation pressure in the new extensions to 650 psig, to increase generator and primary distribution voltage from 2,300 to 12,000 volts, and to re-use the existing 12,000/2,300 volt transformer in the rearrangement.

Preliminary plans, completed late in 1945, for the installation of two new turbine-generators were extended in September, 1946, to include a third unit. In developing the design a model of the generator building (Figure 1) was constructed. It serves as a guide for obtaining the most desirable arrangement in connection with operation, accessibility for maintenance and planning of tie-ins between the old and the new.

Figure 2 shows the same model with roof removed. Two of the three new turbine-generators are in the right foreground and the smaller existing units in the background. The design incorporates an air conditioned control room (left center), overhead cranes, and work space at ground level with roll-up doors of sufficient size for trucking the largest equipment parts in and out of the building (dark section in center).

Figure 3 is a view of the basement showing reinforced concrete columns and beams for floor supports, and conduit runs from existing switchgear, in background, to new switch bay in left foreground.

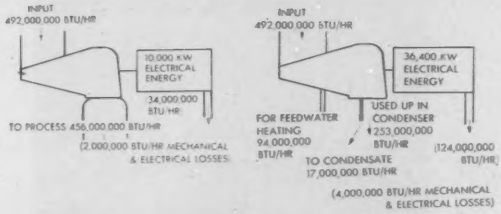
The three main turbines are designed for steam conditions of 630 psig throttle pressure, 750 F throttle temperature, and 200 psig exhaust pressure. The generators are 3-phase, 60-cycle, 12,000 volt units designed for 10,000 kw at 0.8 power factor, or 12,500 kw at unity power factor, but with maximum efficiency at 10,000 kw. Each generator is provided with a 250 volt, 50 kw direct-connected exciter.

The turbines are of the impulse-reaction type with solid forged spindles, grooved for the direct setting of individually milled 13 percent chrome steel blades. The generator rotors, exciter rotors and turbine spindles are each carried in two pressure lubricated bearings.

A new or existing large capacity low pressure steam system can be used as a base for a superimposed power plant. Steam then flows from new high pressure boilers through non-condensing turbines to the low pressure system. The higher the new boiler pressure, the greater the superimposed turbine plant output—how high is a matter of engineering economics.

Among interesting superimposed power plants are those exhausting to processes that can efficiently use the latent heat in the steam as well as the superheat. The plant addition now under construction by Shell at Houston is a good example.

As a matter of interest a comparison, on a plant basis, of one of Shell's turbines with a condensing turbine operating under equal inlet steam conditions is shown below.



Superimposed non-condensing turbine plant is not charged with heat to process . . . has a thermal efficiency three times that of condensing turbine plant (right).

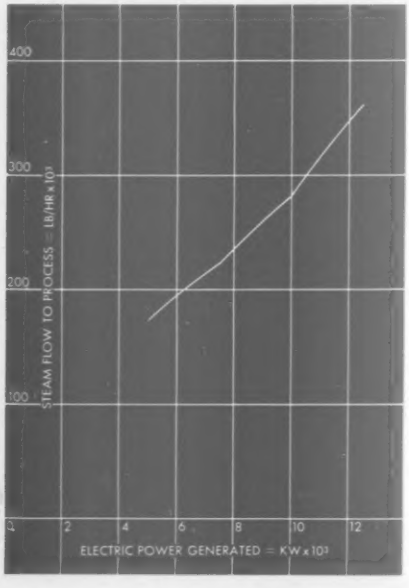
Condensing turbine plant produces over three times the power of non-condensing turbine plant (left) but is charged with heat used up in condenser . . . has lower thermal efficiency.

Each turbine is provided with a speed regulating system which maintains generator synchronous speed. Maximum load protection is provided in each generator output circuit to protect the generator. Each of these devices is a contact-making wattmeter which operates the turbine synchronizing motor and thereby lowers the load whenever the generator output reaches a set maximum. The reduction of generator output will not curtail operation of the plant because electric power is purchased to meet peaks and other supplemental requirements, nor will decreases in steam flow from main turbine exhausts curtail the supply of 200 psig steam to process because pressure regulated reducing and desuperheating stations are provided in steam by-passes and adequate boiler capacity is available.

Plan includes special auxiliaries

Additions or modifications to the standard accessories provided for the turbine-generators are fire protection equipment of the carbon dioxide type to serve all units, space heaters in the closed air cooling system to prevent damage to generators by condensation of acidic moisture during shutdowns; twin oil coolers which permit cleaning of one while the other is in operation; fans and filters to draw cooling air through the exciters from the basement; incidentally ventilating the basement; and duplex low pressure gauges across the last rows of turbine blades to indicate the possible build-up of deposits on these blades.

The turbines are of the superimposed or non-condensing type, designed to generate power while reducing the pressure of high pressure steam and exhausting to the 200 psig supply for refinery processes and power plant auxiliaries. The electric power generated, therefore, is approximately proportional to the amount of steam exhausted to process. The curve (Figure 4) indicates this relationship. Steam generating capacity is economically limited to the peak demand for the process system.



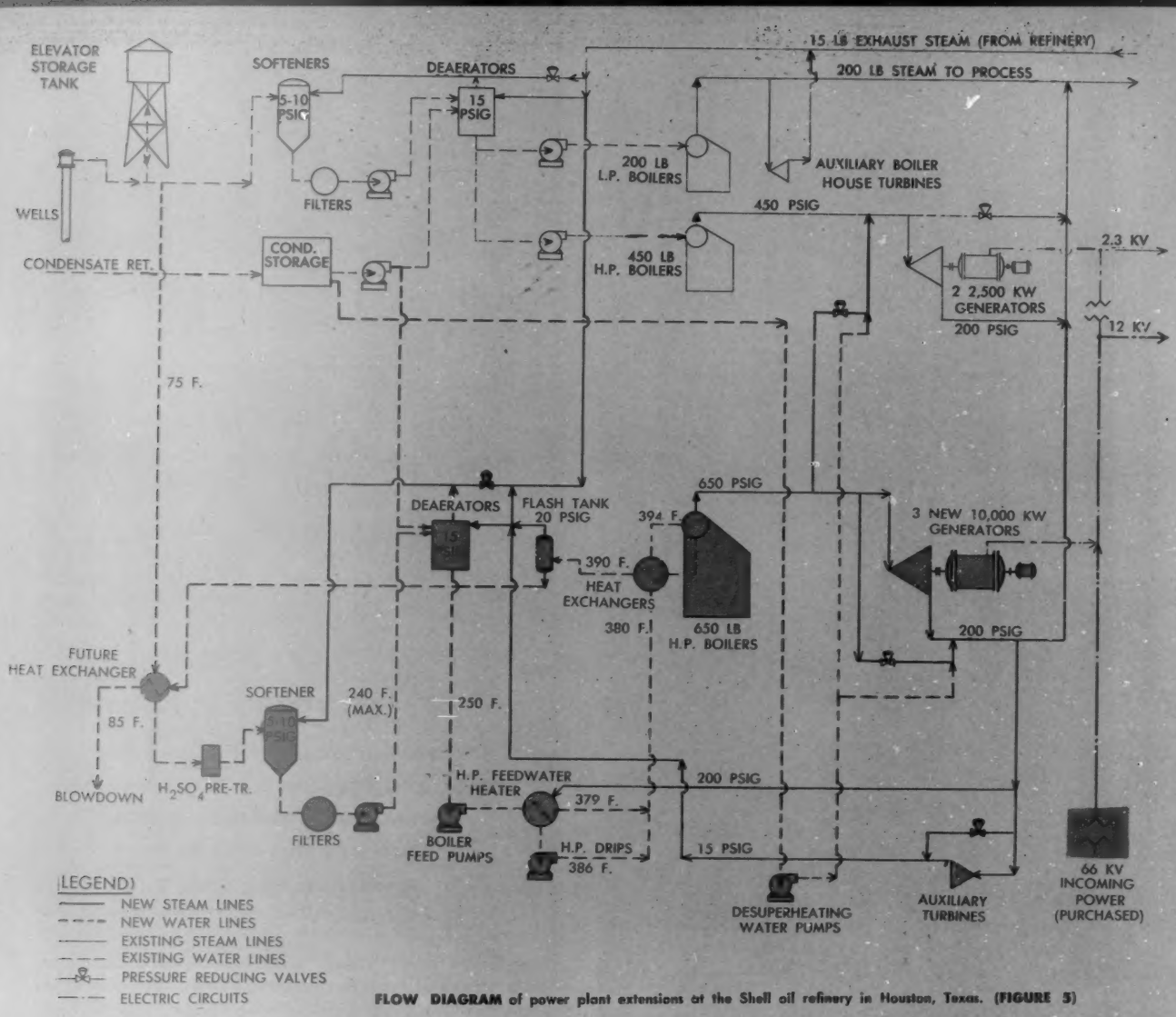
LINE DIAGRAM relationship of steam flow to process and electric power generated by one 10,000 KW turbine generator. **(FIGURE 4)**

The main advantage of superimposed turbine-generators, in refineries which use large amounts of process steam, may be demonstrated by comparing the heat requirements of such an installation with those of the conventional condensing turbine-generator of approximately the same size (10,000 kw) and initial steam conditions (630-650 psig at 750 F). For example, the superimposed turbine-generator will take about 3,610 btu per kwh from steam on its way to process; whereas the condensing installation requires 12,000 to 13,000 btu per kwh, of which some 70 percent comprises heat losses in the condenser.

The use of non-condensing turbines, therefore, superimposes efficient electric power generation on the refinery's processes which in themselves are efficient consumers of heat from steam. This may be demonstrated by a brief description of the process. About 25 percent of the total process steam goes to closed coils and heat exchangers in which the residual superheat and all the latent heat are transferred to process. The condensate is returned to the power plant. The remainder is divided among steam drives, stripping operations and miscellaneous uses. Steam supplied to drives for pumps, compressors, fans, etc., is admitted at 175 to 200 psig and exhausted to a 15 psig collecting system (except for a few outlying units which exhaust to atmosphere). This low pressure system supplies heat to closed coils, heat exchangers and to the water softeners and deaerators at the power plant. Where steam is used in direct contact with petroleum fractions or chemicals for stripping operations, the available heat is efficiently used but the condensate generally is contaminated and cannot be economically returned and treated for boiler feedwater.

The current extensions are shown with heavy lines in Figure 5. Raw water (about 75 percent of the total make-up) is given a sulphuric acid pretreatment for reduction of high bicarbonate alkalinity, aerated for carbon dioxide reduction and then softened in a hot lime process. Heat is supplied to the softener by the low pressure exhaust system which gathers steam at 15 psig from auxiliary power plant turbines and steam driven refinery equipment. Provisions are made for injecting phosphate in the storage compartment of the softeners or direct to boiler drums. This method of treatment has replaced the hot lime-gypsum process with a resulting decrease of 53 percent in the cost of chemicals. Treated feedwater and condensate are deaerated before being pumped through two closed stage heaters.

The first closed heater, shown in Figure 5, as the high pressure heater, uses 200 psig steam from the main turbine exhaust as heat medium and the condensate or high pressure drips are returned as boiler feedwater. This stage heater permits an increase in electric power generation of about 19 percent over and above that which can be generated with steam supplied to process and auxiliary turbines. The additional electric power is generated at a net thermal efficiency of 73 percent (95 percent for non-condensing turbine-generator multiplied by 80 percent net boiler efficiency and further reduced by 3 percent to allow for radiation). This is almost three times the thermal efficiency that would be attained by a condensing turbine installation. The flow follows a circular pattern from boilers through generator turbines and stage heaters and then back to the boilers.



FLOW DIAGRAM of power plant extensions at the Shell oil refinery in Houston, Texas. **(FIGURE 5)**

The second closed heater, or high pressure continuous blowdown heat exchanger, conserves heat at a high temperature level.

Next in the line of flow in Figure 5 are the new high pressure boilers. The economic pressure and temperature for steam generation were found to be 650 psig and 750 F. Process steam requirements are not quite large enough for the generation of all electric power loads with superimposed turbine and these initial steam conditions. Higher throttle pressures and temperatures, however, would involve appreciable initial investment for equipment, water conditioning, and piping for which there is no economic justification with loads as projected.

Turbines by-passed during down time

During normal operation, practically all of the steam from the high pressure boilers flows to the turbine-generators with only a relatively small amount flowing through the pressure reducing valves which by-pass the main turbines. This by-pass arrangement not only permits the generators to take load variations but also assures a steady supply of steam to the processes during either emergency or planned generator outages. The temperature of steam to process is controlled by injecting condensate on the downstream side of the pressure reducing valve for desuperheating.

Power plant auxiliary turbines are designed to take steam at 200 psig and to exhaust at 15 psig. The steam for these auxiliaries is efficiently used since it is generated at 650 psig, expanded through the main turbines, further expanded through the auxiliary turbines; then it supplies heat to, and is condensed in, the feedwater softener and deaerator; and finally the condensate is returned with the feedwater to the boilers.

The first of five 650 psig boilers and half of the water treating plant extensions have been in successful operation since September, 1946. The second and third 650 psig boilers and the first two 10,000 kw turbine-generators are scheduled for completion in 1947, and the balance of the extensions in 1948.

Thermal Balancing of Large Rotors

By W. F. KING
Mechanical Engineer, Electrical Department,
Allis-Chalmers Mfg. Co.

Vibration caused by uneven rotor heating can be isolated and corrected. Methods given here are the first to be published anywhere.

A temperature difference of less than one degree across the diameter of a long rotor can warp the shaft sufficiently to cause an undesirable degree of mechanical unbalance and ensuing vibrations. This unbalance is entirely distinct from that caused by unsymmetrical weight distribution although it results in vibrations similar to that of static unbalance. Normally it appears when the rotor is raised to operating temperature after having been balanced at room temperature. Furthermore, this bow of the shaft, which is not eliminated by the addition of the usual balance weights, will cause eccentricity at the coupling end of the shaft or at the commutator of an overhung exciter.

Thermal unbalance is the effect of either unsymmetrical heating or cooling of the rotor body, a condition which probably exists to some degree in most electrical machines. Fortunately, it is too slight in most instances to be detected. When thermal unbalance is of minor magnitude, suitable correction can be made by mechanical balancing at optimum operating conditions. This need for balancing some large rotors under load conditions has been recognized in literature dealing with field balancing of rotors. However, when thermal unbalance is of relatively large magnitude, thermal correction is necessary.

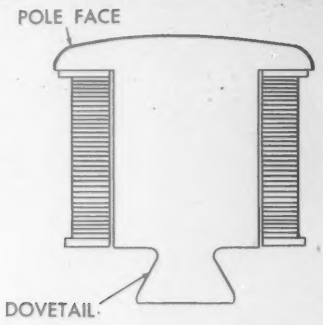
This type of unbalance changes with rotor temperature and can be detected and distinguished from other factors causing vibration by its characteristic behaviour. Changing a factor affecting rotor temperature, such as the field current of a synchronous machine, will produce a gradual change in the unbalance which will continue until the rotor temperature becomes stable. The time interval from the change in operating conditions until vibration remains uniform may be one-half hour or several hours, depending on the size (thermal capacity) of the rotor. Failure to take this time lag into account may lead an observer to believe the balance is erratic. If the vibration changes immediately upon changing the field current, the unbalance is magnetic, i.e., caused by defective field winding or unsymmetrical magnetic circuit: if the vibration changes immediately upon change in load, it can be attributed to a faulty coupling or a load effect on the prime mover.

Bowing of the shaft from thermal unbalance can be detected by checking the shaft runout at different rotor temperatures. Runout should be checked as far from the bearing as possible. The bowed shaft will produce axial forces on the pedestal, and vibrations in the axial direction will be large compared to the horizontal and vertical vibration.

For a given diameter and temperature difference, the deflection will vary approximately as the square of the rotor length. In other words, a rotor whose length is great in proportion to the diameter will be sensitive to thermal unbalance. Temperature effect is therefore generally encountered in large synchronous condensers and large turbo generators.

Thermal balancing of a salient pole rotor

The first step in correcting thermal unbalance for a synchronous condenser type machine is the measuring of temperature at each pole. After a load run of sufficient duration



FOR ACCURACY temperature measurements should be taken at the two points marked on the above pole piece. **(FIGURE 1)**

for rotor temperature to reach a condition of equilibrium determined by observing the vibration trend, the machine is shut down. Temperatures of each rotor pole face and dovetail (in order to insure more consistent accuracy) are meas ured at both ends of the rotor immediately after the rotor comes to rest (see Figure 1). Measurements must be prompt to avoid the temperature gradient built up during the load run from dissipating by conduction through the rotor body and being masked by natural convection which cools the lower side of the rotor. Since a temperature difference of only a few degrees is to be found, it is essential that measurements be carefully made. Furthermore, repeating tests two or more times is conducive to greater accuracy.

Figure 2a shows the method of plotting actual temperatures encountered on a typical ten pole synchronous condenser. The difference between the average temperature of each pole and the mean temperature of all poles is tabulated for each test run. Separate tabulations are made for the pole face and dovetail temperatures. Deviation of the temperature of each pole from the mean temperature is then averaged for all test runs and a circle of any convenient diameter is drawn to represent the mean temperature of all the poles. Average temperature deviation of each pole from the mean temperature is plotted to scale using the mean temperature circle as a base, thus providing a magnified view of the rotor temperature variation.

In the case shown in Figure 2(a), the hottest poles were, by coincidence, grouped together. The diagram is obviously unbalanced about the center of the circle. A balanced diagram can be worked out by using the same values for average deviation from mean temperature and rearranging the poles. This can be checked by cutting out a cardboard polygon of the anticipated balanced diagram as shown in Figure 2 and pivoting it on a pin through the center of the circle. A solution involving the least work in changing poles is chosen from among the several possible arrangements.

The diagram of Figure 2(b) was obtained by rearranging the values plotted in Figure 2(a). Actual temperatures measured by test, after interchanging pole 2 with pole 4 and pole 5 with pole 9, are charted in Figure 2(c). The results were entirely satisfactory. Balance weight correction is necessary after rearranging poles.

AVERAGE DEVIATION from mean temperature for the poles of a typical synchronous condenser is plotted below. Using thermocouples, two men can take a complete set of readings in less than ten minutes. **(FIGURE 2)**

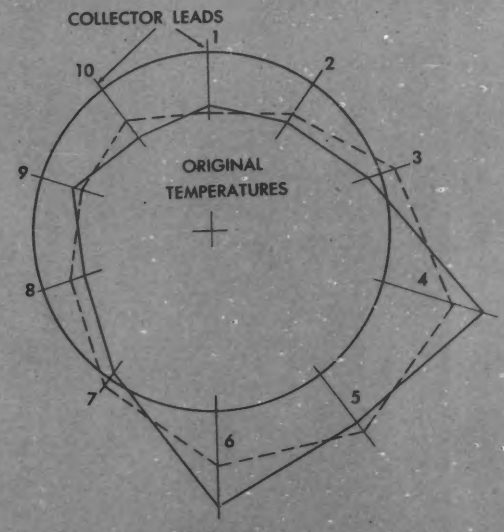


FIGURE 2a

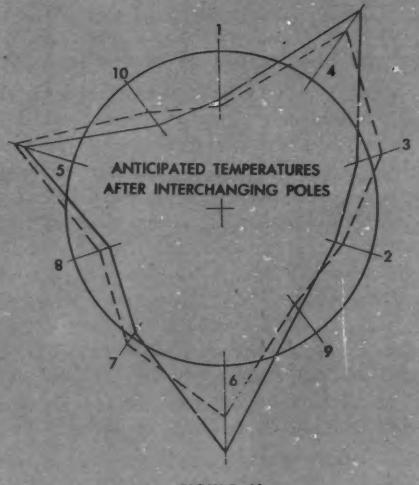


FIGURE 2b

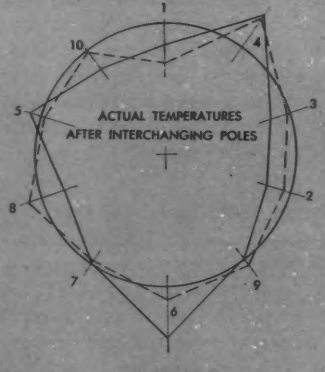
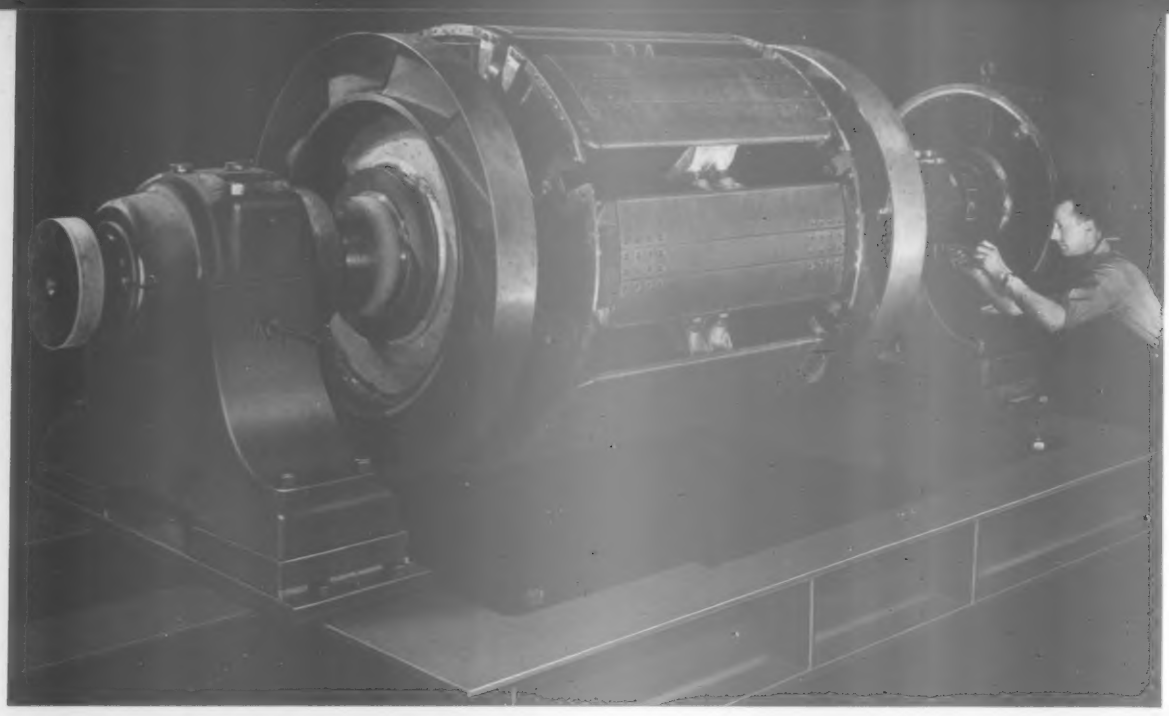


FIGURE 2c

NUMBERS are the original pole numbers.
CIRCLES represent mean temperature (not to scale).
BROKEN LINES connect dovetail temperatures.
SOLID LINES connect pole tip temperatures.



Thermal balancing of a turbo rotor

An altogether different procedure is used for thermal balancing of turbo rotors, since the temperature difference that will cause undesirable vibration is slight and access to the rotor for temperature measurement is often difficult. Here balancing is accomplished by inserting obstructions in the rotor ventilating ducts much as one would add static balance weights, and the vibration trend as the rotor temperature changes is used to determine the location and magnitude of thermal correction. The change in rotor temperature is preferably brought about by simply changing the power factor while holding load constant. Ample time must, however, be allowed for establishing equilibrium conditions. Subsequent runs for checking the effect of a change in the rotor ventilating system should duplicate conditions of the initial run.

The vibration data is plotted on a polar diagram as shown in Figure 3a. Taken at regular intervals, this data will, under conditions of thermal unbalance, show a definite trend as the rotor temperature changes. The direction of the trend with increases of temperature is the same as if static weight were added to the warmer side of the rotor. Hence, the location at which a rotor cooling slot is blocked is the same as that at which weight would be added if the unbalance were purely a matter of weight correction. The magnitude of the correction must be determined by trial, and usually the necessary corrective measure can be closely estimated after one trial correction.

Temporary blocking of the discharge openings of rotor cooling slots has been done by inserting blocking strips into the slots through the generator air gap. While this is a painstaking, difficult operation it saves the time required to withdraw and reassemble the rotor. Rotors (Figure 4) having a length to diameter ratio sensitive to thermal unbalance are provided with means for blocking the rotor cooling slots at the ends of the rotor.

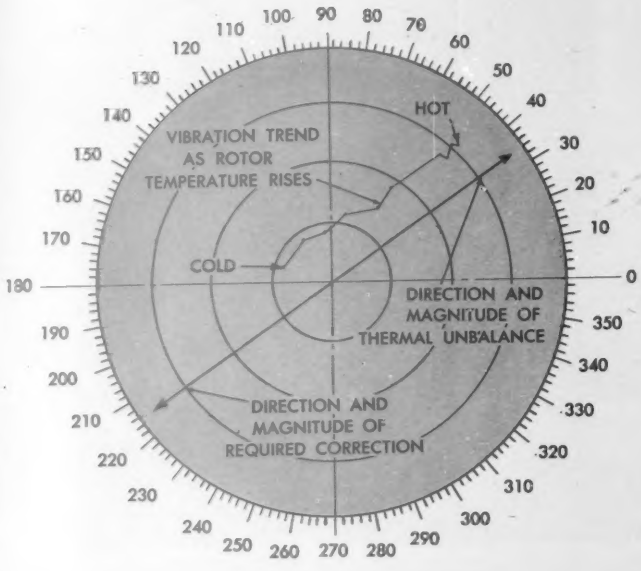
Following a modification of the rotor cooling system to compensate for thermal unbalance, it will be found that the vibration will undergo a transient variation while the rotor temperature is changing, but will return to the original condition when the temperature becomes stable. A typical transient vibration pattern is shown in Figure 3b.

Laminations can cause shaft warp

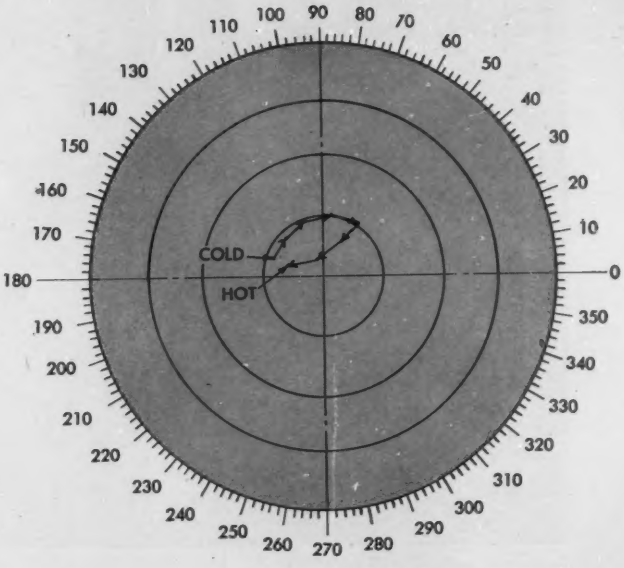
Bowing of shafts and behaviour analogous to thermal unbalance is sometimes found in high speed induction motors and direct current machines where laminations are mounted directly on the shaft and clamped at the ends by a retaining plate secured to the shaft. Variation in the build-up of parts, which may arise from a slight accumulative variation in the thickness of the laminations, will cause a difference in the pressure between laminations diametrically across the rotor. Under assembly conditions, the difference in pressure may not be sufficient to deflect the shaft perceptibly, since the core, owing to the inherent waviness of the laminations, acts like a spring.

In operation, the core will be warmer than the shaft and the interlaminar pressure will increase, for the tight side may be compared to a spring compressed to an approximately solid condition. This may lead to bowing of the shaft and consequent unbalance which will increase with rotor temperature. Partial reduction in the clamping pressure on the rotor core usually brings the unit back in balance.

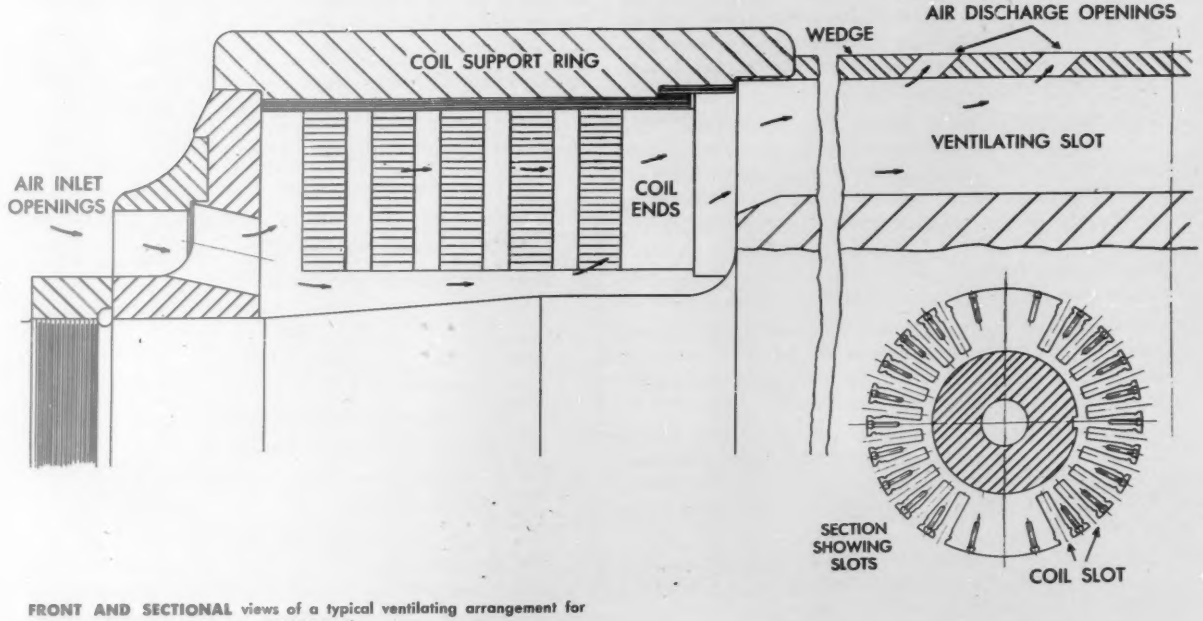
When we consider the many dissimilar materials entering into the construction of a rotor and the wide variation in their physical properties, it is not surprising that thermal unbalance presents such problems, particularly where the ratio of the rotor diameter to its length is high. In spite of these problems, balancing can be done in a surprisingly short time by carefully analyzing each step in the balancing operation, before making any corrective changes.



MAGNITUDE AND DIRECTION of vibration are taken at one bearing pedestal at regular intervals during warming up period. **(FIGURE 3a)**



THIS TYPICAL pattern of a transient vibration condition was achieved after necessary thermal corrections had been made. **(FIGURE 3b)**



FRONT AND SECTIONAL views of a typical ventilating arrangement for a long turbo-generator rotor. **(FIGURE 4)**

Selecting a Low Voltage Breaker?

B. HOLMAN
Switchgear-Engineering Section
Allis-Chalmers Mfg. Co.

WHEN a job calls for a low voltage air circuit breaker the selection of the proper rating calls for careful consideration of a number of factors. Often first cost is weighed against the degree of protection desired.

Before any circuit breaker can be chosen, however, the circuit characteristics of the systems must be analyzed. Then the breaker can be selected considering: 1) continuous current rating, 2) type of protective device and, most important, 3) interrupting capacity. Both the continuous current rating and interrupting capacity of a breaker are expressed in amperes in low voltage (250 volts d-c or 600 volts a-c maximum) breaker practice. This rating does not change with voltage as it does in higher voltage work. (See Figure 1.)

The continuous current rating of an air circuit breaker should be equal to or greater than the full load current of the circuit or, in the case of a motor load, equal to or greater than the one hour rating of the motor.

Standard circuit protection practice calls for one breaker pole and an overcurrent trip device in each ungrounded line; however, on three-phase, three-wire systems two overcurrent trip devices will provide ample protection from overcurrents and short circuits.

In taking up the analysis of a system and how its characteristics will affect the choice of breaker sizes, consider a three-phase a-c circuit supplied by a power transformer, with a motor load on each feeder as shown in Figure 2. If a fault occurs at X, the short circuit current can be calculated by means of the following equations.

If the interrupting capacity of breaker P or of the primary circuit is not known, a system of unlimited capacity should be assumed. Then the short circuit current on the secondary of the transformer is $I_{sc} = \frac{(100)\ I_{fl}}{\%X}$

I_{sc} = short circuit current in rms amperes
I_{fl} = full load current of transformer
$\%X$ = percent reactance of the transformer

If the short circuit capacity of the primary circuit is known, then the short circuit current is calculated as follows:

$$I_{sc} = \frac{P \times 1{,}000}{\sqrt{3}\ E \left(\frac{P}{T} \times \frac{X}{100} + 1 \right)}$$

I_{sc} = short circuit current in rms amperes
P = primary short circuit capacity in kva
T = transformer rating in kva
E = line voltage
X = reactance of the transformer in percent

The magnitude of the short circuit current shall be considered as the total rms current plus the direct current component measured one-half cycle after the inception of the fault. The short circuit currents as computed by the above

equations should then be multiplied by 1.25. This factor increases the total current, as computed above, to include the effect of the d-c component which may be present one-half cycle after the start of the fault current.

The inertia of motors 2 and 3 causes them to act as generators for the duration of fault current. The average motor will feed approximately five times its full load current into the fault and this current must be added to the short circuit current of the transformers when determining the duty on the circuit breakers.

For ease in computing short circuit current contributions from rotating machines the following assumptions can be made. If the circuit voltage is 120/208 volts, assume 50 percent of the total load consists of motors; therefore, add 2½ times full load current of the transformer to the transformer short circuit current as the motor contribution to the fault. On 240, 480, and 600-volt circuits assume that the entire load consists of rotating machines; then five times the transformer full load current should be added to the transformer short circuit current as the motor contribution to the fault.

Applying full capacity breakers by the conventional method shown in Figure 2 is the safest since each breaker is capable of interrupting the maximum fault current, and a fault on one feeder will only cause a minor disturbance to the other feeders.

Cascading as an economy measure

It is not always economical, however, to apply circuit breakers in the conventional method. If the load consists of an assembly line or related processes which make it necessary to shut down all circuits should one operation stop, a cascaded arrangement of breakers can be used. This system is shown in Figure 3.

When employing this arrangement only breaker A must have a continuous current rating larger than the continuous current rating of the transformer. Breaker A should be adjusted to trip instantly on fault currents equal to 75 percent of the interrupting rating of breaker B. Breaker B can be applied in a circuit where the total fault current amounts to 200 percent of its rating. Breaker C can be applied in a circuit where the total fault current amounts to 300 percent of its interrupting rating.

Further cascading is an unsafe practice. Breaker B¹ of Figure 3 should trip instantly at current values equal to 75 percent of the interrupting rating of breaker C.

Suppose that in Figure 3 the interrupting capacity of the primary breaker is 150,000 kva, the transformer is rated 1,000 kva, five percent reactance with a 480 volt secondary, with a 100% motor load. The continuous rating of the transformer =

$$\frac{1{,}000 \times 1{,}000}{\sqrt{3} \times 480} = 1{,}200 \text{ ampere}$$

For this continuous current the breaker A will have an inter-

Current Rating Amps.	Interr. Capacity Amps.	Frame Size Amps.	Magnetic Trip		Thermal Trip	
			Inv. Time % Rating	Inst. Trip % Rating	Inv. Time % Rating	Inst. Trip % Rating
25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225	15000	225	100-200	1000 100-200	100-150	1000
50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 275, 300, 350, 400, 500, 600,	25000	600	100-200	1000 100-200	100-150	1000
200 225, 250, 275, 300, 350 400-500 600	50000	600	100-200	1500 100-200 9000 AMPS	*	*
800	50000	800	100-200	1500 100-200 1500	*	*
1000 1200	50000	1200	100-200	1500 100-200 1500	*	*
1600	50000	1600	100-200	1500 100-200 1500	*	*
2000 3000	75000	2000 3000	100-200	100-200 1200	*	*
4000 5000 6000	100,000	4000 5000 6000	100-200	100-200 1200	*	*

FIGURE 1

*This is a non-adjustable instantaneous trip coil which is set at the factory. It normally bears this relation to the continuous current rating of the breaker.

Thermal overcurrent trip coils are calibrated with a 24° C. ambient temp. Increase calibration 1% for each 2° C. temp. rise of ambient temp. above 24° C.

Overcurrent trip coils can be supplied as per any single horizontal line according to breaker capacity.

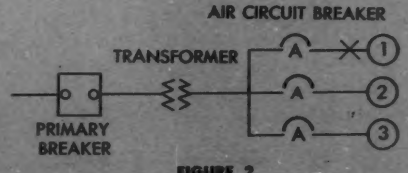


FIGURE 2

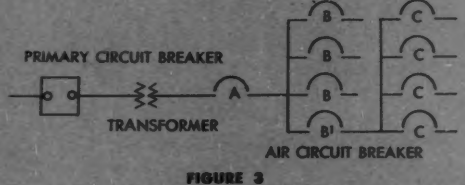


FIGURE 3

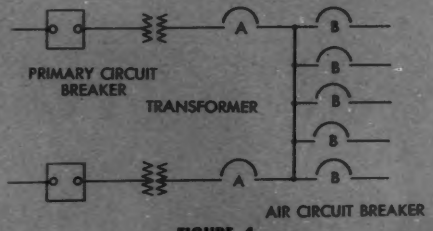


FIGURE 4

rupting rating of 50,000 amperes.

$$I_{sc}\ (\text{Trans.}) = \frac{150{,}000 \times 1{,}000 \times 1.25}{\sqrt{3} \times 480 \times \left(\frac{150{,}000 \times .05}{1{,}000} + 1\right)}$$

$$= 26{,}600 \text{ amperes}$$

I_{sc} (Motor load) $= 5I_{fl} = 5 \times 1{,}200 = 6{,}000$ amperes
Total short circuit current $= 26{,}600 + 6{,}000 = 32{,}600$ amperes.

Therefore, breakers B and C in Figure 3 would require interrupting ratings of 25,000 and 15,000 amperes, respectively.

Usually breakers are cascaded in steps according to their interrupting capacities, such as 75,000, 50,000, and 25,000 AIC (ampere interrupting capacity) breakers; however, in some cases the main breaker has an interrupting rating of 75,000 amperes and the feeders 25,000 amperes. This is ordinarily required when the continuous current rating of the main breaker must be over 1,600 amperes, which is the largest continuous rating of a 50,000 AIC breaker. All other rules of cascading apply.

All breakers with a continuous current rating of 25 to 1,600 amperes can be supplied with dual magnetic overcurrent trip coils. This type of protective device has an inverse time characteristic on overload currents and trips instantly at approximately ten times the breaker's continuous current ratings. These overcurrent trip coils can be adjusted between 100 and 200 percent of their current carrying capacity. However, adjusting the trip setting to 200 percent of the trip coil rating does not actually increase the continuous current rating of the breaker. The inverse time characteristic of this protective device can be increased or decreased by turning a small oil cup mounted below the trip coil. This operation varies the area of the oil film between two machined discs which must be broken before the breaker will trip on overcurrent.

Air circuit breakers with an interrupting capacity of 75,000 amperes have either inverse time delay or instantaneous trip coils adjustable between 100 and 200 percent of their rating, or they are supplied with non-adjustable instantaneous trip device, set by the manufacturer.

Air circuit breakers with a continuous rating from 25 to 600 amperes and an interrupting rating of not more than 25,000 amperes can also be supplied with thermal-magnetic trip coils which are adjustable between 100 and 150 percent of the breaker rating and trip instantly at approximately 10 times rated current. They have an inverse time characteristic which is similar to the heating curve of the motor they are protecting and will not trip because of the large starting currents of the motor. This type of overcurrent trip should only be used on single a-c motor feeders. The thermal magnetic trip coil will not operate on direct current circuits.

When more than one source of power is available, the short circuit currents from each source must be calculated and added together to find the total short circuit current.

For example, in Figure 4, the primary short circuit capacity is 250,000 kva. Transformers are rated 1,500 kva, 6.5 percent reactance, and 480 volt secondary with 100 percent motor load.

$$I_A = \frac{1{,}500 \times 1{,}000}{\sqrt{3} \times 480} = 1{,}800 \text{ amperes}$$

$$I_{sc}\ (\text{Trans.}) = \frac{250{,}000 \times 1{,}000 \times 1.25}{\sqrt{3} \times 480 \times \left(\frac{250{,}000 \times .065}{1{,}500} + 1\right)}$$

$$= 31{,}600 \text{ amperes}$$

I_{sc} (Motor load + Trans. 1) $= 5 \times 1{,}800 = 9{,}000$ amperes
I_{sc} (Motor load + Trans. 2) $= 5 \times 1{,}800 = 9{,}000$ amperes
I_{sc} (Motor load) Total $= 18{,}000$ amperes
Total short circuit current $= 2 \times 31{,}600 + 18{,}000 = 81{,}200$ amperes.

Since breaker B can be applied at 200 percent of its interrupting rating, a 50,000 AIC breaker can be used. Although the largest current the main breaker would have to interrupt would be 49,600 amperes, the continuous current of 1,800 amperes makes it necessary to apply a 75,000 AIC amperes interrupting capacity breaker because the maximum continuous current rating of a 50,000 breaker is 1,600 amperes.

Using the 75 percent rule for breaker A, the main breakers should trip instantaneously when the fault current is approximately 75 percent of the interrupting capacity of breaker B or 37,500 amperes. Therefore, the main breakers should be adjusted to trip instantly when the current flowing through them equals $\frac{31{,}600 \times 37{,}500}{81{,}200}$ or 14,600 amperes, since the fault current is being supplied from two sources.

Breakers connected in cascade may be justified for many installations, where economy is of prime importance. Yet, this is not considered good engineering practice and there are several limitations to the system which should be taken into consideration.

1. Breakers should not be cascaded when a fault on one feeder may cause an undesirable shut down of other feeders, as in the ventilating system of a cleaning line or in parts of a continuous chemical process.

2. On severe short circuits the main breaker should interrupt or at least assist the feeder breaker in interrupting the short circuit. Since the feeder breaker may be subjected to current values two or three times its interrupting rating, each feeder breaker should be inspected and possibly overhauled before replaced in service after each outage due to overcurrent tripping.

Direct current circuits

There is a definite limit to the commutating rate of direct current machines, usually about 200 percent of the continuous current rating. Air circuit breakers, therefore, which are to protect direct current machines, should have a continuous current rating equal to the one hour rating of the machine and should be provided with instantaneous overcurrent trip coils calibrated at 100 to 200 percent. Where the safety of the machine must be sacrificed for the continuity of service, dual magnetic trip coils which have a 100-200 percent calibration and will trip instantly at approximately 10 times the breaker rating can be used.

When used with two-wire generators, air circuit breakers should have one overcurrent trip coil in each ungrounded line. When used with three-wire direct current generators, they should have full capacity overcurrent trip coils in the lines and approximately a 50 percent capacity overcurrent trip coil in neutral.

If the direct-current generators contain compensating windings and are connected in parallel, equalizer connectors are required. The compensating windings of the generator can be connected to the equalizer bus by means of knife switches,

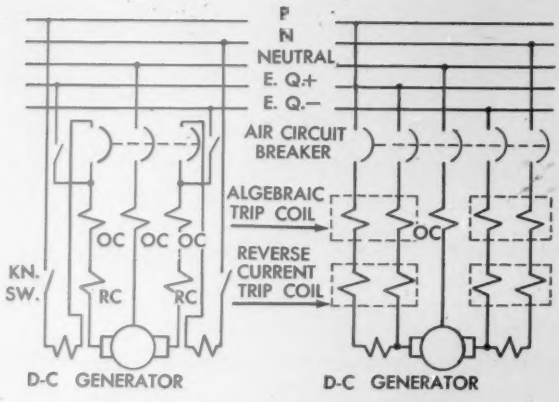


FIGURE 5 FIGURE 6

as shown in Figure 5. The overcurrent trip coils in the lines of the generator must carry full armature current; therefore, two extra lines are required to connect the compensating windings to the equalizer bus and a connection must be made between the overcurrent trip coils and the contacts of the breaker. This is often difficult because the coil is usually made integral with the breaker mechanism.

Use algebraic trip coils

Under these conditions a five pole breaker should be used with algebraic trip coils, as shown in Figure 6. Here the line and equalizer current flow through two separate windings, which are on one magnet and affect a single armature. When the current flows through the line and equalizer poles in the same direction, its effect on the algebraic trip coil is additive and will trip the breaker when the sum of the two current values reaches a predetermined value. When the current in the line and equalizer poles flow in opposite directions, it is subtractive. Although the current normally flowing in the equalizer circuit is small, the resistance of the circuit must also be small, to be effective. Therefore, the current rating of the equalizer pole should be about 50 percent of the line pole, keeping the breaker contact resistance at a minimum.

When direct-current generators are operated in parallel, the air circuit breakers should also be equipped with reverse current trip attachments. One reverse current trip attachment should be used on two-wire generators and two on three-wire generators; although, however, one reverse current trip attachment is often employed in a three-wire generator at some sacrifice of machine protection.

The reverse current trip attachments consist of one potential coil and one current coil mounted on a common magnet. Under normal conditions, these two coils buck each other; but on reverse current the coils operate together, attracting an armature. Movement of this armature causes the breaker to trip.

The choice of the proper breaker, whether large or small, becomes a problem of weighing economics against the degree of protection required, keeping in mind all of the possible faults that might occur in any part of the circuit involved and the effect of these faults on the remainder of the system.

NEW PRODUCTS

New Slip Ring Enclosures Eliminate Explosion Dangers

Industry proven slip ring enclosures are now available for use in installations which only rarely operate in the presence of explosive gas mixtures and which do not warrant the added expense of complete explosionproof motor construction. In instances where the use of open type wound rotor and synchronous motors is permissible, slip ring enclosures provide sufficient protection against the ignition of explosive gases by sparks at the brushes. A further economical advantage of the enclosures is that they can also be used with totally-enclosed, explosion-proof machines.

Slip ring enclosures are of welded construction and consist of a one-half inch steel case with three-quarter inch flanges and a babbitted shaft labyrinth seal which is three and three-quarter inches long. The front end cover and welded flange are made of pressed steel. Because the machined flange surfaces permit sealing with a special sealing compound, no gaskets are required between the case, cover, and shaft seal. Fan blades mounted on the slip ring assembly provide air circulation within the enclosure, while the enclosure itself is kept cool by outside radiation and natural convection.

Standardized Steam Turbines Cut Production Time, Costs

Faster deliveries, lower costs to the purchaser and standardized ratings, steam and extraction nozzle conditions are among the principal advantages offered by the new line of standardized steam turbine generator units now under design and construction. Presently restricted to six sizes ranging in capacities from 11,500 to 60,000 kw, the uniformly designed and manufactured units will enable planning engineers to obtain certified drawings and begin foundation design immediately after contract clearance.

Besides enhancing the general appearance of the new turbine units, streamlined jacketing provides protection for the throttle valve, inlet piping, control valve chest, governor control mechanism, oil piping and gland steam and auxiliary oil pump regulators. Although jacketing is designed to improve appearance and protect heat insulating material, enclosed parts are readily accessible for inspection and maintenance.

MORE FACTS about these new products are available on request. Write the Allis-Chalmers ELECTRICAL REVIEW, Allis-Chalmers, Milwaukee 1, Wisconsin.

TIME STOOD STILL for 1/6,000 of a second when the turning of this solid-forged, alloy steel spindle for a 10,000 kw condensing turbine was photographed on the production floor with a strobo-flash camera. Spindle is one of four for similarly rated turbines now under construction for a large mid-western utility company.

Something New every day!

J. G. LINN
Service and Erection Department
Allis-Chalmers Mfg. Co.

Erection engineering may at times exhaust an engineer's ingenuity, versatility and patience, but its challenges sharpen his interest.

A SERVICE and erection engineer must be a jack-of-all-trades in erection techniques besides being a specialist on some particular type of machinery. In addition, he should be versed in many fields to meet successfully situations arising from the various installations he is called upon to complete. Ingenuity and a flexible personality are equally essential qualifications for his job which aid him to cope with complications when installations demand that he assume the status of advisor, conciliator, supervisor, laborer, technician, expediter, and company good-will representative during the various stages of any particular assignment.

His responsibilities, like his qualifications, also cover a broad field. A service and erection engineer assumes charge of equipment from the time it leaves the shipping department until it is installed and operating, and accepted by the purchaser. This obligation extends only to larger size or special equipment posing special erection problems, since small or standard machines seldom require his services in any other but trouble-shooting capacity.

Demands on his ability are as varied as the types of installation he is called upon to complete. It may include welding anything from a cement kiln to a mine hoist; rebuilding a transformer; rewinding an armature on a 10 hp d-c motor or a 10,000 kva a-c generator; erecting a complete steel mill drive with controls, or installing control apparatus varying from electronic regulators to water rheostats.

Or the work may require unloading and handling heavy equipment in the field without appropriate cranes, special blocks, and rigging gear ordinarily used for similar purposes in the home [illegible]. Unloading giant castings and parts for a hydro-electri[illegible] at a remote railroad siding, transporting them over [illegible] roads to an isolated backwoods site, and erecting it without the use of a crane is a rule rather than an exception for service and erection engineers skilled in handling this particular type of equipment.

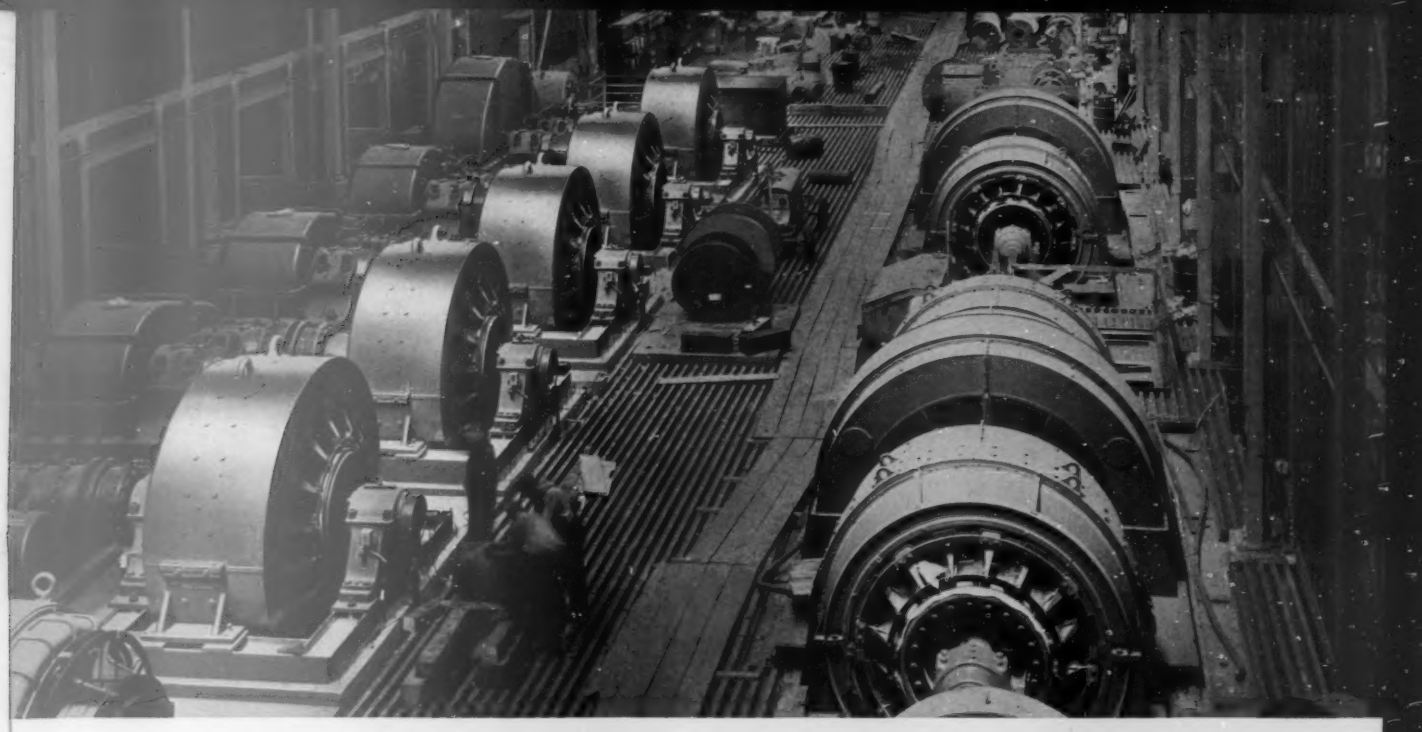
General erection procedure

One of the best ways to outline an erection engineer's problems is to follow through a typical installation such as one of rotating electrical equipment where the following general procedure is the rule:

1. Check equipment on hand for shortages, breakage, etc.
2. Determine what parts are needed first.
3. Move machines and equipment to field.
4. Level up bases and check couplings; level up rotors and check and adjust air gaps and magnetic centers, check pedestal installation; clean and assemble bearings.
5. Grout in base.
6. Make final alignment check.
7. Check insulation of motors and generators (dry out).
8. Connect motors; install bus work and wiring.
9. Dry out after insulation check, if needed.
10. Start set for rotation.
11. Make bearing run.
12. Make permanent connection after switchgear and starting equipment has been checked.
13. Check control and machinery for operation.
14. Put into service.
15. Operate equipment for short time to catch any trouble.
16. Run complete unit on regular load.

When equipment is shipped, the erection engineer is supplied with a shipping manifest listing all parts, their condition, weights, etc., together with car number and routing or truck line used. Shipments may be contained in a single box or crate or include several railroad cars, depending on the installation.

After the material arrives at its destination, it is checked against the manifest for shortages and shipping damage. Rigging and handling needs are determined by weight listing. Since shipping manifests list all parts, they help to decide



which cars or parts are to be unloaded first, and which can be stored or set aside for later use, allowing parts to be placed for minimum handling during erection.

Installing rotating machinery

Assuming that a job requires the erection of a motor-generator set with switchgear and simple control, it should also be assumed that the foundation for the m-g set and switchgear is already in since these preliminary steps are usually handled by the purchaser. As soon as the material is unloaded, the base of the m-g set is moved to the foundation, placed, and leveled with shims at points of greatest stress.

After the base is leveled and bolted down, the stator for the motor and field yoke for the generator are placed on the base, followed by the placement of bearing pedestals and alignment of parts. Large multi-machine sets, sometimes of several machines, require bases up to 65 ft in length, with five or six bearing pedestals. These sets may be aligned by stretching a steel wire between the two end pedestals and centering it in both of them. Remaining pedestals are then checked against the wire to make sure that all bearings are in line and that the wire is centered in all stationary members of the machines which in this case would be the armature of the a-c and field yokes of the d-c machine.

The next step is to clean the shafts of all rotating parts. These are then put into place with the shafts resting on the lower half of the bearing in the bearing pedestal. When an installation consists of several machines, rotating parts would first be placed in the center machines and work would progress from the center toward each end until all rotating units are in place. Placement of rotating parts is followed by the leveling of shafts of each unit with a level placed on the shaft directly above the bearing, allowing for a natural deflection or sag in the shaft caused by weight. Adjustments, if necessary, are made by shimming the bearing pedestals.

Alignment of couplings on the shafts between units is very important. These must be aligned with painstaking care to make certain that all members are rotating on the same center line. Most prominent among the troubles caused by misaligned couplings are vibration and undue bearing wear and heating. Overheating can be averted by checking all bearings to ascertain that no bearing carries more than its proportionate share of the weight.

Bearings and oil reservoirs must be cleaned carefully, oil rings checked, and bearings spotted by "bluing" the shaft to make sure there are no high spots in the bearing which will prevent an oil film from forming between shaft and bearing. An ideal bearing is one in which there is no contact between shaft and bearing when the machine is in operation since the shaft rides on a high pressure oil film. Drilling a small hole near the "load line" and installing a pressure gauge would reveal pressures of several hundred pounds on the oil of a running bearing at the "load point."

After bearings have been checked and couplings made, bearings caps are put on and covered to keep out dirt. Air gaps between rotor and stator are then checked to make sure that the rotating member will be in the center of the magnetic field radially and axially. Failure to have the rotor centered along the magnetic axis may result in end thrust on the bearings or bumping of the rotor against the bearings on sudden load changes. In the case of a d-c machine, a radially uncentered rotor or stator may result in noise, vibration, or commutation troubles.

Assembling the brush arm and spacing brushes, the next operation, is followed by checking of brush arms to see that all brush holders are in line and parallel with commutator bars. The clearance between brush holders and commutators is checked to ensure that the brush rides the commutator at the proper angle of contact and that the spring tension on the brushes is satisfactory.

While this is going on, part of the crew has been getting the switchgear cubicles moved into place and ready to be energized. The driving motor can then be connected preparatory to starting the motor-generator set for checking rotation. Prior to this, extensive checks must be made to determine

that no loose parts or foreign objects are in the machine or windings, and that all coupling bolts are secured.

When coils leave the manufacturer they are thoroughly dried and impregnated with insulating compound varnish but, during the several weeks or months that may elapse before a unit is put into service, they will necessarily absorb a certain amount of atmospheric moisture which, on higher voltage equipment, can be serious. Unfortunately, there is no easy way of checking insulation resistance in the field until after the coils are actually placed in the unit.

When machine insulation is checked, coils with a poor insulation value must be dried until the insulation resistance reaches a safe value. The most commonly used practical methods of drying are:

1. Run an enclosed turbo or a hydro unit at no load.
2. Short circuit the unit and run it on full current; or put d-c through stator windings.
3. Blow heated air through machine.

Once the coils and terminal connections have been checked satisfactorily the bearing caps are removed and bearings checked for cleanliness and condition. Bearings are then assembled, oil rings checked, oil placed in the oil reservoirs of the bearings, or, if bearings are force-lubricated, the lubrication system is filled and checked for proper operation.

With everything in shape, the motor is "bumped" or turned on momentarily to see whether it is running in the right direction and that nothing is rubbing to prevent free rotation. The oil ring on each bearing, or the oil flow gauge, is checked while the motor is "coasting" from its "bump" to assure that all bearings are receiving proper lubrication. If everything works satisfactorily the unit is brought up to speed and run for 30 minutes to an hour. Bearings are checked for heat and the unit for vibration during this test speed run. The base is then carefully grouted and the cement allowed to set for 24 to 48 hours before the machine is run again.

After the grouting is set, the machine is started and run continuously from 8 to 16 hours for a bearing run to make sure that all bearings will operate without vibration or undue heat. After the bearing run, the machine is shut down and prepared for loading: all covers, base plates, etc., are put on, and all remaining connections made. The unit is then operated under load and checked to see whether any further adjustments are to be made before the machine is declared operationally satisfactory. Trouble will seldom develop during these test runs if the outlined erecting procedure is followed.

The general procedure for installing the switchboard and automatic control for an m-g set such as this consists of the following steps. Locate and set up the board, machines, and switchgear, and check circuits for continuity, ground, and sneak circuits. Insulation of all circuits should be checked, and all recording and indicating meters should be tested and calibrated. The wiring, of course, may include hundreds of individual circuits interlocking with other circuits through relays and other control devices.

Final adjustments for actual operating conditions are made after circuits have been checked and control energized. Sometimes, these may differ from theory because of individual variations in machines and techniques of various operators. All operators do not have "ideal" operating techniques and the control must be revised to make it proof against such operations. Because of this, automatic control circuits often become very complicated in attempting to forestall errors on the part of the operator and protective devices for machines have become legion.

Easier methods learned through experience

Many quicker and more expedient methods have been evolved through meeting various problems under different conditions. One of the most useful tools is a general text book on the equipment involved in a particular installation. A study of the subject while on the job can be tied into an actual experience.

No story by an erecting engineer would be true-to-style without including a few pet short-cuts, and this one will be no exception.

Utilizing exciting currents to an advantage is an excellent example of saving time in locating trouble. They can be used for locating shorted turns in stator windings, locating "bad" connections in "damper" windings, and locating shorted turns in field windings of synchronous or other fields, as well as locating shorted turns in transformers and relay coils.

Supposing that shorted turns exist in a star-connected stator winding of an a-c machine (Figure 5), and assuming that coil group 3 in phase C is defective, we excite A and B from low voltage, say a 110 volt source, and measure the exciting current, say it is 2 amperes. B and C may be 8 amperes, and A and C may be 8 amperes since two groups including C have high current. It would then be assumed that the trouble is in phase C. Further checking can be done by exciting A to N, B to N, and C to N. After locating the defective phase, individual pole groups in this phase can be excited until the defective pole group is located.

Individual field poles can be checked for loose damper bars or defective field coils by taking one individual pole group in any phase and placing a field pole directly under it. Brushes should be lifted from the slip rings while this is being done so that the field will not be closed through the discharge resistor. On one job I recall, loose damper bars in a synchronous motor caused individual exciting currents to vary from 19 to over 30 amperes. The lower readings were on field poles with loose bars. The loose bars were not discernible by close inspection until individual bars were tried and paint scraped from brazed connections.

In another typical example, exciting currents were used in testing to locate shorted turns of a three-phase to six-phase, 13,800 volt to 625 volt to neutral, 5,500 kva transformer. It was determined on which of the three legs and on which end of this leg a fault was occurring before the transformer was opened. When opened, it was found that an accidental ground in two places to the core of this leg was allowing currents to circulate through the core. Ratio voltage, resistance, and insulation checks on this transformer failed to indicate the fault although it did reveal itself in bubbles of smoke when the transformer was loaded.

Locating shorted turns on relay coils is relatively simple and well known to engineers. The excitation current of a simple transformer as that shown in Figure 6 is recorded. The relay coil in question is dropped on the open leg of the transformer and the excitation current is again checked. Short circuited turns on the coil under test cause the excitation currents of the transformer to rise.

"ONE FOR THE BOOKS"

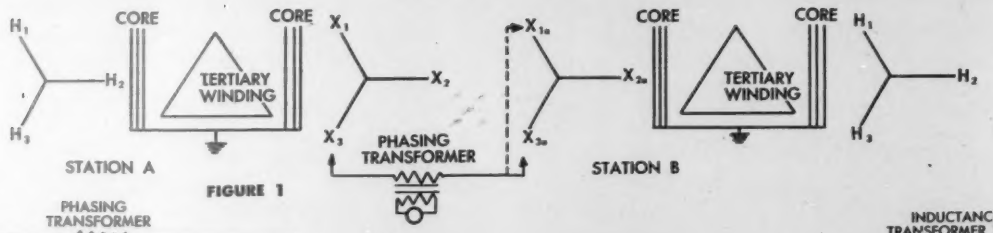


FIGURE 1

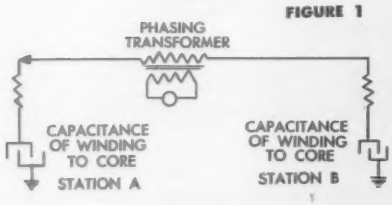


FIGURE 2

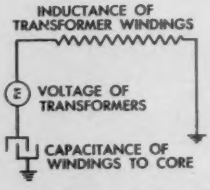


FIGURE 3

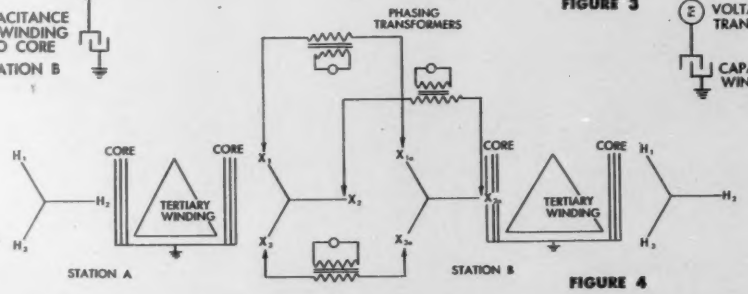


FIGURE 4

THE importance of understanding the theory underlying the operation of electrical equipment was brought home pretty clearly on one job a few years back. We were called on to replace bus insulation on a disconnect switch in an outdoor substation operating at 13,800 volts. This bus had flashed over to ground and destroyed the insulators.

Something was obviously wrong, since the bus insulation had been tested at 39,000 volts to ground before leaving the manufacturer. There were two similar substations and the fault had occurred while the user was phasing out the two units for parallel operation. In phasing out they had removed all grounds from the neutral of both transformers besides removing the grounding transformers, and proceeded to phase out using one phasing transformer.

Both substations were fed by individual transformer banks connected wye-wye with a delta tertiary winding to reduce third harmonics. The hook-up is shown in Figure 1. When the phasing out transformer was hooked between X1 and X1a everything was satisfactory, but when it was hooked between X1 and X2a the disconnects flashed over to ground.

It is evident that in using one phasing out transformer and no grounds on the system being phased out, the only return circuit was through the capacitance of the winding of each transformer to the core, which is grounded, and, as each transformer winding has inductance, a circuit results such as shown in Figure 2.

Thus a capacitance and inductance in series and a circuit that might be series resonant was encountered. See Figure 3. It was calculated that with the atmospheric conditions prevailing at the time, at least 80,000 volts were developed between the bus and ground! After new insulators were installed the two transformer banks were phased out successfully by using three phasing transformers (Figure 4) with no indications of high voltages. — *J. G. Linn*

Finding brush neutral in d-c machines

One of the most common of all problems following the installation or repair of d-c equipment is that of locating the electrical "neutral" position of the brush rigging. The following procedure has been the most accurate of any that the author has found over many years of experience.

The "neutral" is located by energizing the interpole while the machine is running full speed. It must be taken with the shunt field de-energized and the residual voltage from the shunt poles at zero or as near zero as is practical. In

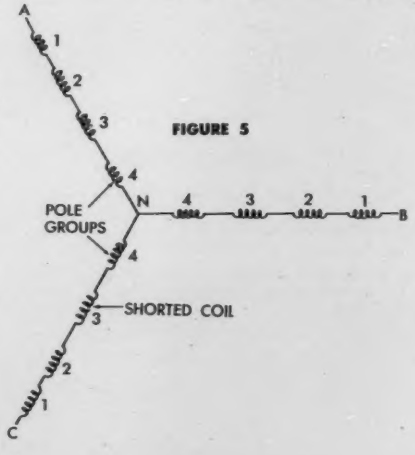


FIGURE 5

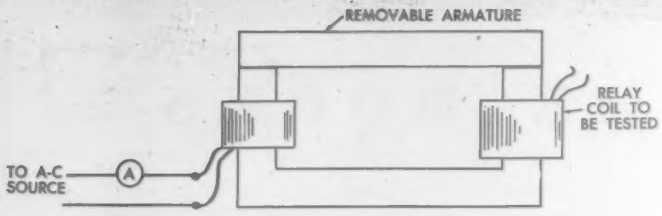


FIGURE 6

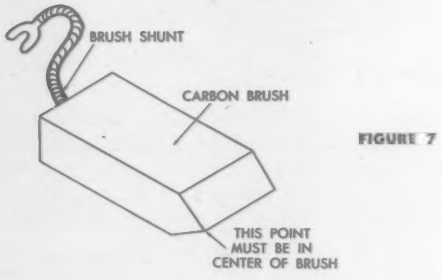


FIGURE 7

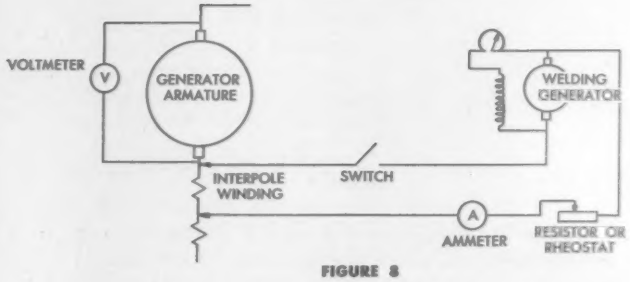


FIGURE 8

using this method on a d-c motor it becomes necessary to drive the motor by some other mechanical source.

Residual voltage from the shunt field may be "bucked" out by using a reversing switch and an independent d-c source of about 20 percent of full value from the shunt field. This voltage may be applied to the shunt field through the reversing switch at the proper polarity and lengths of time until the residual voltage of the fields is killed.

In using this method it is necessary to raise all brushes from the commutator. At least two brushes must be made to fit each brush holder so snugly that they have no play. These brushes must be accurately pointed, with the point in the exact center of the brush (Figure 7). This point should be no wider than the slot between commutator bars.

Brush arms must be accurately spaced around the commutator. If the number of commutator bars is exactly divisible by the number of brush arms, the arms may be so placed that all pointed brushes fall into commutator slots. Otherwise, spacing may be done by using a piece of paper, such as an adding machine roll, and encircling the commutator. When the brush arms have been spaced and the residual of the machine brought to zero, with the machine running full speed, the interpoles are excited with about 2 percent of full load current from a suitable source, such as a welding machine (Figure 8).

If brushes are on the neutral point and the residual voltage is zero, the voltage between positive and negative brush arms will be zero. If it is not zero, the brush rigging is moved until the voltage included in the coils under the interpoles reads zero on the volt-meter placed across positive and negative brush arms. When this is done, the excitation of the interpoles can be raised to 4 or 5 percent of full load current, and the voltage should remain at zero. In fact, raising the excitation to 10 percent full load should not change the zero reading.

If there is no residual in the main poles, the voltage should still read zero when the excitation is removed from the interpoles. Should residual voltage appear when excitation is removed, it should be "bucked" out and the test repeated.

In the event that it is impossible to reduce the main pole flux to zero and some small amount of residual remains, the brushes should be moved until this voltage does not change when interpoles are excited or unexcited. If there is, for example, .15 volts residual with interpoles unexcited and .10 volts with interpoles excited, it means that the interpole is bucking down the residual by .05 volts. This can be remedied by moving the brush riggings a few thousandths of an inch until the voltage remains .15 volts whether the interpole is excited or not. When this point is reached, the interpole excitation should be increased to 10 percent full load and then reduced to zero. No change in the .15 volts across the brush arms should be apparent.

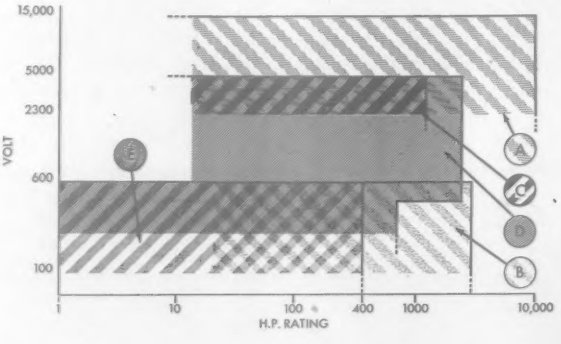
This method of establishing neutral is more accurate than that of "flashing" the neutral because it is checked with the machine running and the coils passing under the interpoles are being excited from the interpole as in actual operation. As a further check, the interpole excitation may be reversed and checked as before. The results should be the same.

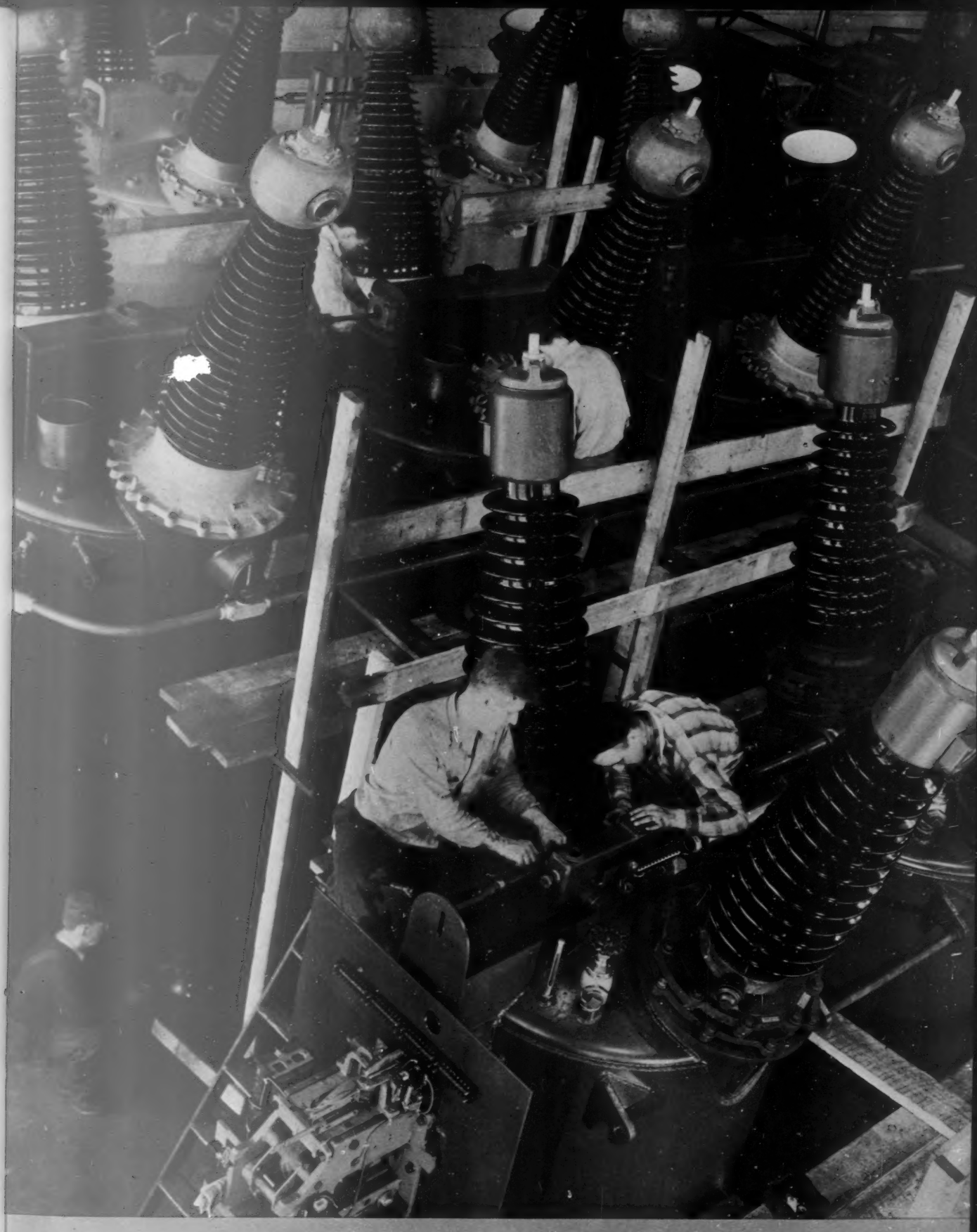
Almost every service engineer who has spent more than a few years "on the road" has developed, often through necessity, many time-saving and ingenious methods of handling problems that must be solved on the spot. While installing and trouble shooting power equipment is seldom easy, it is always interesting. It is a job where ingenuity is often of more value than a knowledge of theory, and where handling men can be a bigger problem than handling machinery.

CORRECTION

Many readers caught the error in the placement of three of the symbols in the motor starter ratings chart included in John Baude's "A Survey of Modern Motor Starters" page 21, First Quarter, 1947 issue. The corrected chart appears at right. We suggest that you mark your copy accordingly.

In addition, the three different maximum horsepower ratings for type "D" starters in the table under the chart on page 21 refer to synchronous, squirrel cage and wound rotor motor starters respectively.





POLE MECHANISMS and controls being installed on three-phase circuit breakers which are being processed on the breaker assembly floor in ever increasing numbers these days. Units are rated 138 kv, 2,500,000 kva and all have five-cycle interrupting and 20-cycle reclosing speed.

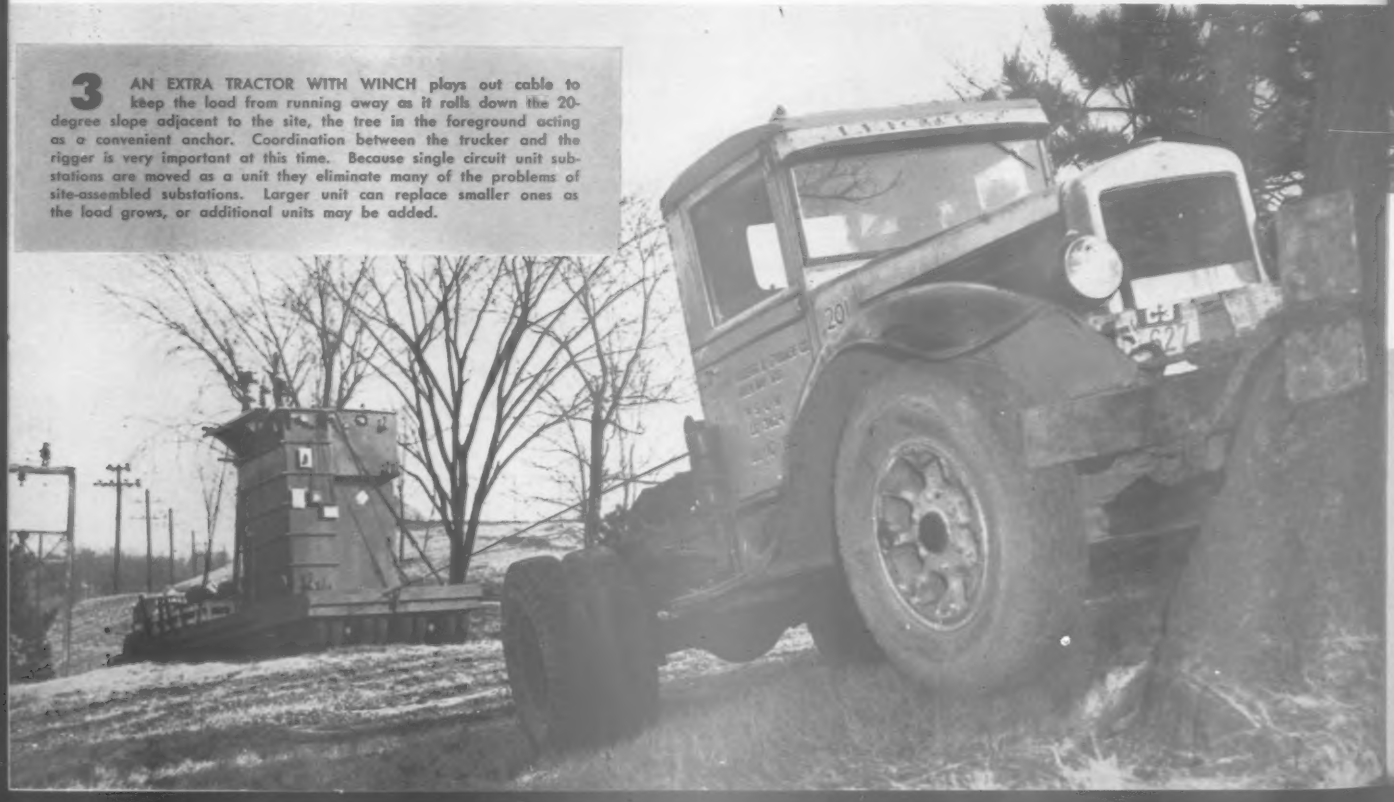
Installing a Unit Substation

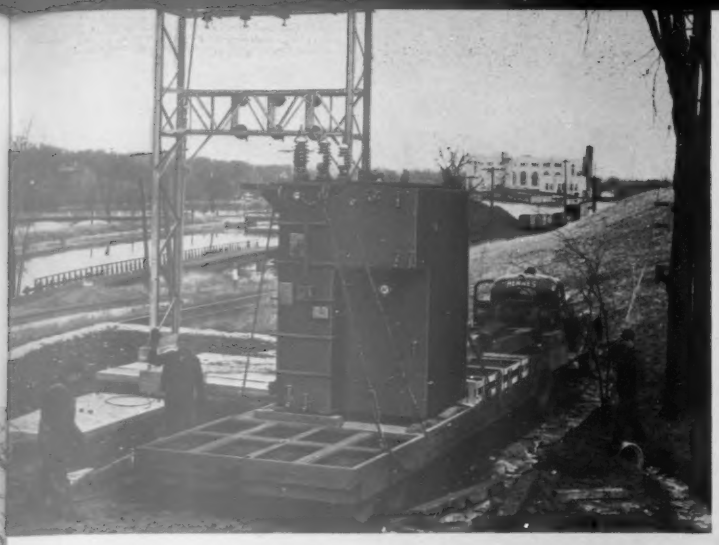
By: JOHN McGUIRE and W. E. SCHWARTZBURG
Mixed Apparatus Section, Electrical Department
Allis-Chalmers Mfg. Co.

1 **A COMPLETE 1500 KVA UNIT SUBSTATION rolls along a midwest highway nearing the installation site. Within this single enclosure is a 1500 kva transformer, load-ratio-control equipment, a power circuit breaker and all necessary relays, meters and instrument transformers. Radiators and lightning arresters were removed to the floor of trailer to reduce height to 12½ feet to clear power lines.**

2 **CARRYING THE 16-TON SUBSTATION, the trailer lumbers across a field. The transformer is located within the ribbed portion of the tank. Behind the hinged door are the circuit breaker, metering and relaying equipment and regulation control panel. The tap changer and inert gas compartments are above the switchgear. Standard drawings of the unit substation were supplied previously and the foundation and steel structure were erected in advance by the utility crew.**

3 **AN EXTRA TRACTOR WITH WINCH plays out cable to keep the load from running away as it rolls down the 20-degree slope adjacent to the site, the tree in the foreground acting as a convenient anchor. Coordination between the trucker and the rigger is very important at this time. Because single circuit unit substations are moved as a unit they eliminate many of the problems of site-assembled substations. Larger unit can replace smaller ones as the load grows, or additional units may be added.**

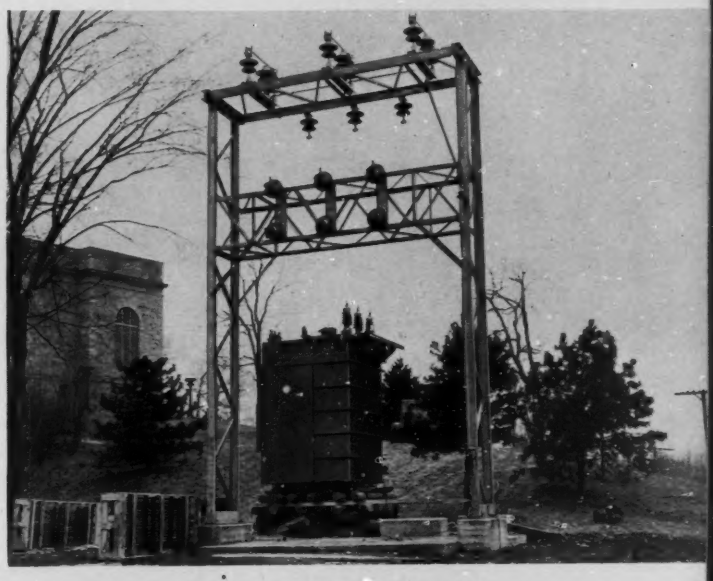




4 THE TRAILER IS BRAKED TO A STOP alongside the foundation. Despite the proximity of the railroad, a trailer proved less expensive in this instance because the river in the background required that the substation be installed across the main line track from the siding. Where load and building conditions allow, it is general practice to locate substations adjacent to a highway to permit the use of mobile unit substations for normal maintenance and for emergency service.

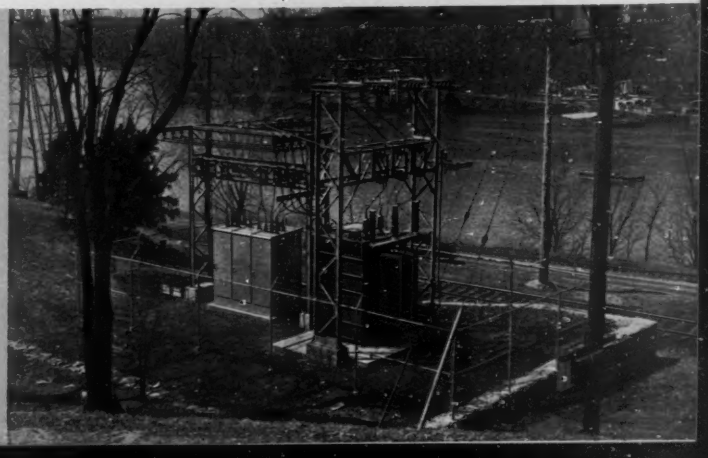
5 MANPOWER TAKES OVER. A crib is erected alongside the trailer and the substation jacked up onto rollers. Bosses on the transformers provide safe jacking points. The riggers have hitched the unit through the towing eyes and are using a cable to roll it onto the cribbing and the trailer is blocked to keep it from moving. Although substations are designed to stand normal skidding and jarring, care in handling is necessary to protect protruding fittings and valves.

6 OFF SHE GOES! As power is applied to the tractor winch, the substation rolls off the trailer onto the cribbing. The winch cable is fed through a pulley anchored to the left of the substation so that it could be moved in the desired direction. The unit still must be rotated 90 degrees so that the primary bushings are in line. Jacks are used to lower the unit onto the single concrete foundation pad.



7 WITH THE JOB NEARLY DONE the truck crew is through. The unit can be made ready for the mounting of the radiators and bushings in a relatively short time. Secondary 4160 volt connections will be made and the transformer section "blown out" with nitrogen. Labor total to this point about 40 man-hours plus supervision. Five hours have elapsed from the time the substation arrived at the site.

8 FINAL SCENE. A protective fence has been added. Although a single circuit sub is normally used only with its own low voltage breaker, three outdoor breakers were moved from elsewhere on the system in this instance. Surrounded with shrubs and grass, the trim looking installation blends with its campus surroundings, presenting an example of good public relations by the power company.



Fundamentals of Automatic Controls

By W. RICHTER
Engineering Development Division,
Allis-Chalmers Mfg. Co.

Hunting remains the control designer's greatest obstacle, but can be overcome by following the advice contained in this article.

HAVING discussed the difference between sensitivity and accuracy in a measuring or controlling arrangement, another set of terms should be explained, namely, "static" or "proportional control" and "astatic" or "floating control." A control duplicating the performance of an operator watching a voltmeter to insure keeping the voltage of a d-c generator at 100 volts, as outlined in Part I, would be termed as astatic or floating control. This term means that the control is theoretically capable of keeping the controlled quantity at an exact value. In the above example the action of the operator is interposed between the indications of the voltmeter and the position into which the rheostat must be brought in order to get the desired voltage value. In other words—and this is very important—there is no functional relation between the position of the rheostat and the indication of the voltmeter. Thus, in order to obtain a voltmeter reading of 100, the operator may find it necessary to move the rheostat to a position near the upper end if, for instance, the generator has to supply a heavy load, while the same 100-volt reading might be obtained with the rheostat setting near the lower end, when the load is light. It is true that the voltage will have to deviate momentarily from the desired value before the operator turns the rheostat, but it is entirely possible for him to bring the voltage back to the

exact value by the manipulation of the rheostat. An astatic type of control keeps on correcting the controlled quantity as long as the latter varies from the desired value.

A static control, on the other hand, must have a permanent deviation of the controlled quantity from the desired value in order to be operative. In practice this deviation may be so little, especially if amplifying techniques are employed, that the performance of a static control may be entirely satisfactory for a given problem. But a clear understanding of the difference between the two types is required since certain problems, such as the control of frequency, absolutely require the use of an astatic type of control.

Circuit of astatic voltage regulator

Let us construct an automatic voltage control duplicating the performance of the operator watching the voltmeter. In Figure 2 the field of the generator G receives its excitation from a separate source B; the variable resistor R is included in this circuit to permit regulation of the field current. It is assumed that on this rheostat all sliding contacts have been replaced by rolling contacts, and that all bearing friction has been reduced to a negligible amount, so that the force necessary to move the arm of the rheostat is extremely small. The generator voltage E is connected to the coil of an air core solenoid in which is suspended a plunger of the weight W. If the plunger were located symmetrically in the exact center of the solenoid, the magnetic force acting on it would evidently be zero; if we should pull it out of the solenoid and dispose it a great distance away from it, the force exerted by the solenoid on it would also be extremely small. Common sense, therefore, will tell us that there must be a position of the plunger which will give a maximum pull on it. If this maximum is rather flat—and by proper construction and design it can be made so—it means that over a small range of positions of the plunger within the solenoid the pull on it will be independent of the position, and will depend only on the voltage applied to the coil.

Assume that the mechanical design of the regulator is such that the full range of the rheostat will be covered with a motion of the plunger in the solenoid over a region where the pull exerted on it is independent of the position. Let it furthermore be assumed that with rated voltage E applied to the solenoid, the pull exerted on the plunger is exactly equal to its weight. Since the pull on the plunger is independent of its position, as postulated, the plunger will fall, and will keep on falling, if the voltage applied to the solenoid is less than E; if the generator voltage is higher than E, on the other hand, the plunger will keep on moving upward. Note that over the operating range of the plunger its action is altogether different from that of a voltmeter: the pointer of the latter would assume a certain position with E applied to it, but would assume a position above or below the latter proportional to the deviation of the voltage E. The plunger, on the other hand, keeps on moving (until the arm operating the rheostat hits a stop) as long as the generator voltage deviates from the value E, no matter how small this deviation may be.

It is evident that this control theoretically, at least, is capable of duplicating the performance of our operator. If the generator voltage falls below E, the plunger starts to move downward, cutting resistance out of the field circuit; as soon as the voltage has reached the value E, the plunger will come to rest in its new position, it weight being exactly balanced by the pull of the coil. The regulated voltage will have the exact desired value, but the plunger will have assumed a different position in the solenoid.

Converting an astatic control to static

Everybody with experience in automatic control will know that the simple scheme described above will be entirely unsatisfactory, if not inoperative, but before discussing the reasons for this, let us see how the simple control shown in Figure 2a can be converted into a static or proportional control. This changeover can be made very simply by the addition of a spring, acting on the plunger; this is shown in Figure 2b. To simplify the discussion, let us assume that the spring can be either compressed or elongated, and that the position of its upper anchor point has been so chosen that, with the rheostat arm in the center position, the spring is exactly in its relaxed state. In the center position of the rheostat arm the spring will consequently not furnish any force in either upward or downward direction, which means that if the rheostat arm is to be in this position, the voltage applied to the coil must have the value E.

Assume that the load of the generator is such that this condition is just fulfilled. When the load increases, the generator voltage will drop. Resistance must be cut out of the field circuit and the plunger must move to a lower position. Whatever position it will come to, it is evident that the spring will be elongated and will therefore furnish an upward pull on the plunger. The magnetic pull of the coil will therefore in this position not have to be equal to the weight of the plunger, as was the case for the astatic control, but only a pull equal to the weight diminished by the force furnished by the spring. This means that the voltage will now be regulated to a value lower than E.

The amount of deviation depends entirely on the deflection factor of the spring acting on the plunger; a very soft spring may perhaps give only a variation of 1 or 2 percent when going from zero to full load, while a somewhat stiffer spring may give a 10 percent variation. It is evident that the successful solution of the problem of paralleling two regulated d-c generators, where usually a small drop in voltage with load must be permitted, may depend entirely on the characteristics of two innocent looking springs in the two regulators.

Hunting is major problem

The most serious difficulty besetting practically all control schemes operating on a closed cycle is the phenomenon of hunting, which will make the simple control shown in Figures 2a and 2b almost certainly inoperative. The control, instead of regulating the desired quantity to a constant value, makes it oscillate around the desired value. If the amplitude of these oscillations around the desired value are relatively large, the control is practically useless; if they are within the tolerance limit of the control, they may not be objectionable, provided that the continuous operation and movement of the control mechanism does not lead to rapid deterioration of the mechanism. A somewhat less serious,

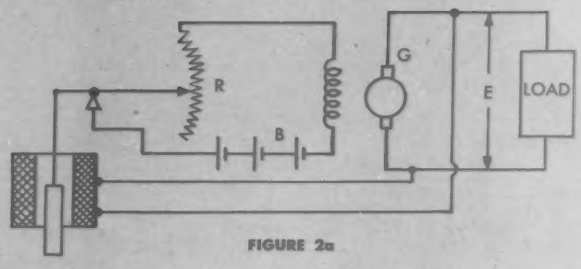


FIGURE 2a

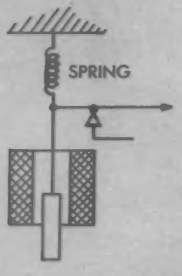


FIGURE 2b

but often annoying, condition is encountered when an automatic control during adjustment to a new set of conditions makes the regulated value describe a series of damped oscillations around the desired value. If a sudden load is applied to a 110 volt generator equipped with a voltage regulator, the voltage may drop instantaneously to perhaps 105 volts. The action of the voltage regulator is supposed to bring this voltage as quickly as possible to the value of 110 volts (in the case of an astatic regulator, or perhaps to 109 or 109.5 volts in the case of a proportional type regulator). With an improperly designed control, however, it is easily possible that the voltage will first shoot up to 114 volts, then drop back to 107, then oscillate to perhaps 112 and after three or four swings come to rest at the new value.

Whether a given control system will exhibit sustained hunting or whether it will accomplish a regulating operation without overshoot can be predicted by solving the set of differential equations applying to the system. This is usually no simple task since the coefficients and factors involved are not linearly related, which makes a complete analytical solution practically impossible. We shall confine ourselves here to pointing out the causes of hunting and the more common methods of handling the problem.

The two most important factors which cause hunting are inertia effects and time lags. A careful analysis of any control system will usually disclose these effects. And, although on the surface they seem to be of an entirely different nature in a control system of temperature, compared to that of an electric generator, they would appear in the mathematical analysis in exactly the same role. Time lags in an electrical control system may be as small as a fraction of a second, while in a temperature control system they may be as long as minutes or even hours. When opening the draft of a coal furnace, no one expects the temperature of the living quarters to rise instantaneously because time is required for an increase in the rate of combustion. Even after this increase has taken place another time lag occurs before the temperature in the living quarters is raised. But in spite of this lesson, the speed with which one quantity affects the other is often disregarded when closed cycle control schemes are designed. If we fail to take into account these time lags and inertia effects in designing a control, we must not be surprised if the regulator performs all kinds of unexpected acrobatics.

Time lags, inertia effects in regulators

Let us now look for the time lag and inertia effects in the control scheme shown in Figure 2a. The first and most appreciable time lag is caused by the inductance of the field winding when we move the rheostat arm from one position to that of a new one with less resistance. The field current will not immediately rise to the value determined by the new position. The generator voltage will, therefore, lag behind the motion of the adjusting rheostat. The voltage of the generator is acting on the solenoid coil; strictly speaking, the pull of this coil on the plunger is determined by the current in the coil, and since the coil has an inductance, a change of generator voltage will not immediately produce a change of pull. Fortunately this time lag is usually so small that it may be safely neglected; it is mentioned here only for the sake of completeness. The plunger and the levers on which the pull is acting all have mass; the force resulting when the weight of the plunger is not completely balanced any more by the pull of the solenoid accelerates these masses which therefore will evidently not reach the newly required position in an infinitely short time. As an additional factor of complication, these masses want to keep on moving, even if the force acting on them has become zero.

With these factors in mind, the analysis of the control action of the circuit shown in Figure 2a is as follows: Suppose that for a certain load condition equilibrium of the control has been obtained with the rheostat resistance about one-half cut out. Now, let the load be suddenly increased, causing the generator voltage to drop. To bring the voltage back to the desired value, let it be assumed that the regulating rheostat must be 75 percent cut out. The decrease in voltage will cause the pull of the coil to decrease with a time lag small enough to be negligible. The difference between the weight and the now reduced pull will act on the mass of the plunger, accelerating it downward. This action cuts out resistance in the field circuit, but will the arm actually come to rest when the 75 percent cut out point has been reached? Due to the time lag caused by the inductance of the field winding the excitation current will not have reached the correct value when the rheostat has reached the position corresponding to the final required excitation. This means that the weight of the plunger exceeds the pull of the coil and the plunger not only keeps on moving in a downward direction, but does so at a still accelerated rate. Thus, the control continues to cut out resistance beyond the point which we know to be correct.

The excitation current in its delayed rise will finally pass through a value giving the correct voltage of the generator. At this instant, or a negligibly small amount later, the weight of the plunger is in exact balance with the pull, but since it was accelerated downward up to this instant, its inertia will keep it moving downward. The generator voltage will rise above the desired value and a force in the upward direction will begin to act on the plunger, decelerating it and finally bringing it to a rest. The final position is considerably beyond the 75 percent cut out point of the resistance. The unbal-

anced force, which has just brought the plunger to rest, will now begin to accelerate it in the opposite direction, although the generator voltage, due to the lag of exciting current may still be rising. Since we now have too high a generator voltage, the control will begin to move toward the 75 percent cut out point of the rheostat, but—just as on the way up—will pass through and beyond it in the opposite direction. It is therefore quite evident that this control will hunt. The reader will realize that the mathematical analysis of the phenomenon will not be very simple, since it must take into account the time lag due to inductance of the generator field and the inertia of the moving parts.

Hunting identical with oscillations

It is evident that hunting is just another word for oscillations, a subject which has been studied intensely by electrical as well as mechanical engineers. In the field of broadcasting the electrical engineer deliberately sets out to find the condition most conducive to the generation of oscillations, while in the design of amplifiers he carefully avoids all conditions which lead to oscillations.

In the past decade a type of amplifier known as "negative feedback amplifier" has found widespread application due to many advantages over an ordinary amplifier. In this type of amplifier a portion, or all of the amplified signal, is fed back to the input terminals in series with the actual signal, with such a polarity as to oppose the original signal. Important improvements in amplifier performance result from this arrangement, but a detailed discussion would be beyond the scope of this presentation. Investigators of this circuit found quite early that the main problem with the circuit was the prevention of unwanted oscillations. The reason for the appearance of unwanted oscillation is the following: no amplifier will amplify signals of all frequencies equally well; furthermore, the amplified signal appearing at the output terminals of the amplifier will generally be phase displaced with the signal applied to the input terminal. Now, if at any particular frequency the portion of the signal fed back to the input terminals happens to be in phase with the signal itself, instead of 180° out of phase (that is, opposing it) then oscillations will start, if the magnitude of the signal fed back is larger than the signal itself.

A comparison of the equations applying to a negative feedback amplifier and to a regulator showed that they had a number of common points, and Prinz and Cage have proposed a novel and interesting approach to the hunting problem in regulators by considering the regulators as negative feedback amplifiers and applying the well developed theory of these amplifiers to the regulators. Space does not permit a detailed presentation of this approach here, but the reader may find the following short discussion helpful in grasping the fundamental idea behind it.

Let the regulator shown in Figure 2 be of the proportional or static type (i.e., equipped with a spring, as shown in Figure 2b). Assume that the generator is operating with a constant load and that the regulator has succeeded in adjusting the voltage to the desired value E. We now place a battery with a voltage E together with a small a-c generator across the coil of the regulator, cutting one of the wires coming from the generator to the coil, so that the solenoid receives its voltage from the battery, independent of the generator voltage. Placing a voltmeter across the two wires coming from the generator, the circuit will now appear as shown in Figure 3.

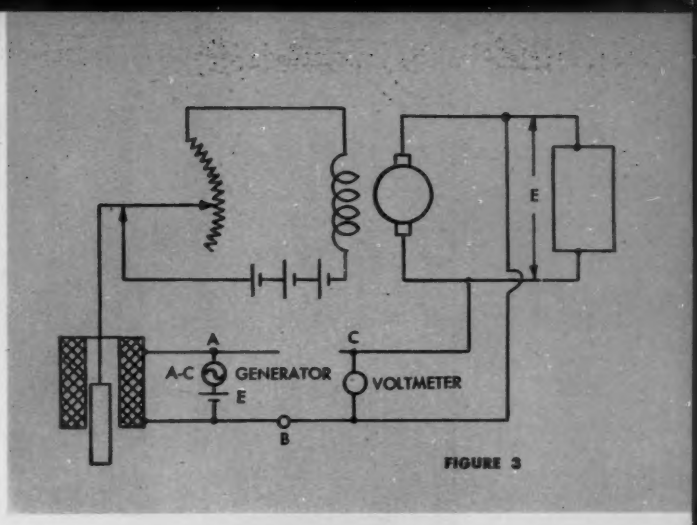


FIGURE 3

As long as the a-c generator does not furnish any voltage, no changes will have taken place either in the regulator system or in the generator.

Now let the a-c generator furnish a small voltage of sinusoidal wave shape with, let us say, one volt amplitude and a frequency which can be varied over an extremely wide range. First, we adjust the frequency of the a-c generator to a very low value, perhaps one cycle per minute, or less. The whole arrangement may now be considered as an amplifier: the input terminals are the terminals of the solenoid coil, while the output terminals are those of the generator itself. With the very low frequency of the a-c generator, the rheostat arm will be able to follow, and so will the excitation current; the variations of the a-c generator voltage will therefore also be of approximately a sinusoidal wave shape. The reader should have no difficulty in seeing that during the time when the small a-c generator output adds to the battery, that is, during its positive half cycle, the voltage of the generator will be decreased; in other words, when the voltage between terminals A and B is increased, the output voltage, that is, the voltage between terminals B and C, will be decreased. The higher the sensitivity of the regulator, the larger will be the voltage variation of point C with respect to point B, and in most practical regulator cases it will be found to exceed the amount of the variation impressed on A.

Analogy to inverse feedback

It is this action which is analogous to the phenomena taking place in inverse feedback amplifiers. Let the frequency of the a-c generator be increased. The inertia of the regulator masses and the inductance of the field circuits will produce two effects: first, the amplitude of the motion of the regulator arm will decrease and the amplitude of the voltage variation observed on the generator will decrease even more, due to the inductance of the field winding. Second, and this is of great importance, a phase shift will develop. If, at any particular frequency, the total phase shift will be such that the voltage between terminals B and C will increase at the same time the a-c generator makes the voltage between terminals A and B increase and, if at this frequency the total amplification of the circuit is still high enough so that the variations of potential of point C are larger than those impressed on point A by the a-c generator, then the regulator would hunt if A and C were connected, and the battery and the a-c generator removed from the circuit. This novel approach permits the analysis of regulators with the aid of

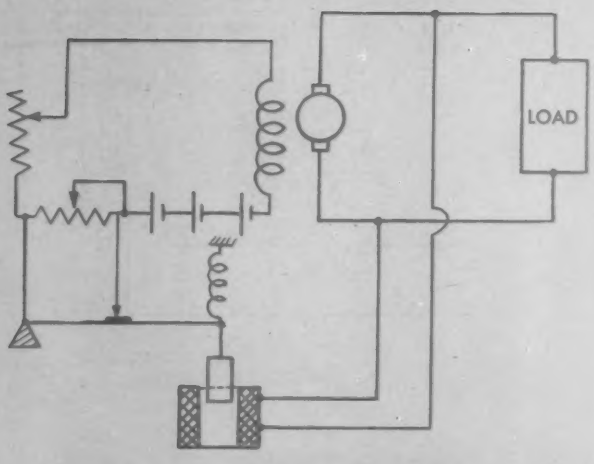


FIGURE 4

equations pertaining to steady state response to sinusoidal excitation. The average engineer is considerably more familiar with these than with the differential equations required for an analysis based on transient response.

This same analysis is also applicable to astatic or floating controls, if we do not let the frequency of the a-c test voltage fall so low that the regulator will hit the end stops. Most readers familiar with the simple voltage regulator used as an example in these discussions know that its tendency to hunt is usually taken care of by the addition of a dashpot to the plunger. Let us analyze what effect this addition would have on the result of the experiment described in the preceding paragraph. For the extremely slow frequency postulated at the beginning of the experiment, the presence of the dashpot would not alter the performance materially. As the frequency is raised to perhaps a few cycles per second, the presence of the dashpot cuts down the oscillation of the plunger and thus reduces the variations of voltage between terminals B and C. If at the frequency at which the potential variations of A and C are in phase, the amplification has been reduced so far that the potential variations of point C are less than those of point A, the danger of hunting will have been eliminated.

"On and off" control

Up to now we have treated hunting as a phenomenon to be avoided in any automatic control. Yet one of the most commonly employed types of controls deliberately makes use of hunting or oscillation. This is the "on and off" type of control with, as the name implies, only two positions: it is in one of these positions when the quantity to be regulated exceeds the desired value, and in the other position when the opposite is true. This is in complete contrast to the action of the regulatory apparatus of Figure 2a, capable of adjusting the field rheostat to any position required to furnish the desired generator voltage. Most of the more familiar temperature controls are of the "on and off" type. Thus the temperature of a flat iron, or the temperature of our home is not regulated by attempting to adjust the current through the flat iron or the oil flow to the burner to just the amount needed to maintain the temperature under the existing load conditions, but by giving alternately full heat and no heat at all, and depending on the averaging effect of the flat iron or the home to maintain the desired average temperature. In such a type of control the regulatory organ simply adjusts the ratio of "on and off" time to a value to produce the desired average result.

With the increasingly important role which electron tubes are playing in automatic control, it may be desirable to point out that a control employing gaseous tubes is fundamentally an "on and off" type of control since these tubes are inherently not able to exercise a choking effect as a vacuum tube does.

The "on and off" principle applied to a generator voltage control gives us the long-known Tirrill regulator. In this system a part of the resistance in the field circuit is continuously inserted and short circuited as shown in Figure 4. The contacts are continuously vibrating, and in order to make their load as light as possible, that portion of the resistance in the field circuit which is being short-circulted is generally made just sufficient to cover the range from no load to full load.

The reader will realize that the very principle of this control calls for oscillation of the controlled quantity around the desired value. It is evident that these oscillations should be as small as possible. Here, again, it is the time lag and the inertia effect of the elements interposed between the regulatory organ and the quantity to be regulated which determine the magnitude of these oscillations. When a typical home heating thermostat calls for heat, its contacts close and the oil burner begins to run. The firepot and the furnace structure in turn heat the air going to the living quarters. When the desired temperature is reached, the thermostat contacts open but since the furnace structure is still in a heated condition the room temperature may keep on rising for a while. Some manufacturers of temperature controls for the home counteract this effect by putting a small electric heater into the thermostat and connecting it in series with its contacts. This small supply of additional heat causes the contacts to open before the room temperature has risen to the desired point.

In analyzing the performance of an "on and off" control the engineer must again carefully investigate all the time lags in the chain of events. If he fails to do so, he may find, as in the case of the floating or proportional type of controls, that the oscillations around the desired operational value are beyond the permissible limit.

Without going into the details of a mathematical analysis, the various types of automatic control have been indicated. Of these the rarely used open cycle type control generally offers no difficulties. But in the design and analysis of any closed cycle control much disappointment and many needless failures could be avoided if we would always keep before us the question, "How fast will one quantity in the chain react to the variations of the quantity preceding it?" The neglect of this question is usually the cause of hunting and, conversely, attention to it will go far towards eliminating costly failures.

BIBLIOGRAPHY

1. D. G. Prinz, Journal of Scientific Instruments, April, 1944, "Contributions to the Theory of Automatic Controllers and Followers."
2. A. Schwaiger, "Das Regulierproblem in der Elektrotechnik." B. G. Teubner, Leipzig and Berlin, 1909.
3. J. M Cage, "Negative Feedback Amplifier Theory Applied to Regulators." Proceedings of the National Electronics Conference, 1944, page 332. (Reprinted in Electronics, January, 1945, page 140.)

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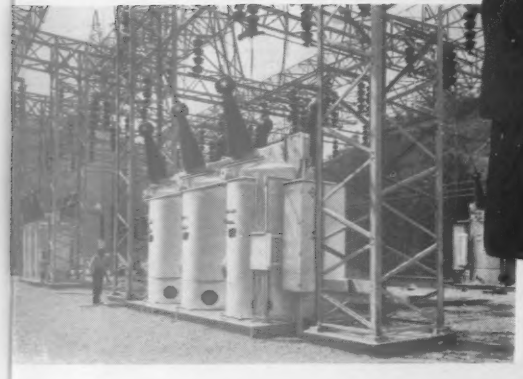

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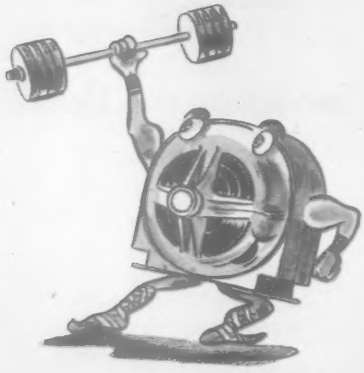

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